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Domestic Spark Arresters

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SUMMARY

An analysis of rural fires in Iowa shows that sparks ejected from house chimneys and falling on combustible roofs account for a large portion of the total fire waste. These sparks originate from soot deposits on the chimney wall, which upon being ignited are loosened and carried out by the chimney gases. If the combustion in the firebox were reasonably complete or if the chimney were kept clean by mechanical means, the soot accumulations would not occur. If the roof were of fireproof or fire-resisting material, the sparks would not constitute a serious problem as is now the case.

The use of a spark arrester, as considered in this manuscript, is an attempt to remedy a bad situation.

Spark arresters have been used successfully on locomotives and industrial chimneys for years. Their application to residences is comparatively recent and a different problem from their industrial use; spark arresters used with success industrially will not operate satisfactorily on dwellings. Therefore this study was made to discover the requirements of a domestic spark arrester, the suitability of a number being offered for sale and the possible design of one which might perform a better service.

In density and in burning characteristics sparks of incandescent soot escaping from the chimney differ considerably from wood embers flying from a burning building. The first section of this study was devoted to a determination of the source and character of these sparks and the condition under which they might ignite both new and weathered wood shingles. Investigations were made of flue gas velocities as may occur in domestic chimneys and those velocities necessary to expel soot particles of dangerous size.

Eleven commercial arresters and four of original design were tested for efficiency in preventing the escape of soot particles when clean and their resistance to the flow of chimney gases when clogged. The conditions which cause the formation of soot and its deposit on the chimney walls also cause deposition on a spark arrester. An arrester which would give satisfactory service on an industrial chimney with a forced or otherwise good draft, and which is closely watched and can be cleaned when necessary, may prove unsatisfactory on a domestic chimney. Many domestic chimneys have insufficient draft even when not equipped with an arrester.

An ideal domestic spark arrester must give at least reasonable protection against the escape of sparks large enough to cause ignition and still not interfere with the draft of the chimney should the arrester become clogged with soot.

The first arresters used on house chimneys provided complete

enclosures with a comparatively fine mesh screen. As the use of these became impossible when even partially clogged with soot, the size of mesh was gradually increased. Vents of various size, shape and location gradually appeared as the result of an effort to provide safety under adverse conditions.

The tests herein described extended over a period of years. All arresters do not appear in each test because some were not available for the earlier tests and some were later discontinued. Techniques were varied largely to determine behavior under a variety of conditions and in an attempt to develop a logical procedure. No precedent was available at the beginning of the test.

Of the spark arresters tested, a number apparently will give satisfactory service when clean and free from soot. In nearly all cases, however, when sooting occurs either the safety is impaired because the soot particles will almost "hunt" the openings or the draft will be so seriously interfered with that the arrester must be cleaned or removed from the chimney. As a result of these studies, an arrester has been devised which both by test as described in this bulletin and by extensive use on chimneys has proved to be efficient and effective. It causes a minimum reduction in draft even when in a completely clogged condition. The free area of this arrester is at no place less than that of the chimney itself.

Domestic Spark Arresters[1]

BY HENRY GIESE[2]

A study of fires in rural Iowa covering the 10-year period 1930-39 (2) showed sparks on combustible roofs to be one of the major known causes of these fires. Figure 1 shows that a very large portion of the waste experienced is the result of burning dwellings. From fig. 2 it is seen that sparks falling on combustible roofs were responsible for 31.2 percent of the damage to rural dwellings from known causes. The total damage was doubtless greater than shown, because under "roof fires" are listed only those fires actually known to be caused by sparks, whereas other fires of such origin will be included among the large number reported as "cause unknown."

From these data it is apparent that rural fires in Iowa could be materially reduced if those from chimney sparks could be prevented.

Prevention is much more necessary in the country than in urban districts. Town fires, even though they occur at night, are usually seen and reported by neighbors or passers-by. Farm fires may be well under way before discovered, and hence usually burn to exhaustion. As shown in fig. 3 the loss per fire is much greater in the country than in town. Many farms do not have telephones. Some time is required to get volunteer fire departments into action. In addition to the handicaps already listed, fire-fighting apparatus going out from town may find the roads impassable or at least difficult as the peak of dwelling fires occurs during late February and March (fig. 4) when roads are likely to be at their worst. Locating the fire may take some time. Inadequate water supply on the farm may make fighting the fire difficult even if the fire department is able to get there before the fire has advanced to the point where it could be stopped without total loss. These illustrations emphasize the importance of a prevention program.

It is not surprising that attention has been directed toward spark arresters. Industry has for years used various devices to attempt to retain sparks within the chimney. Locomotives passing through agricultural sections where sparks might cause

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[1]Project 23 of the Iowa Agricultural Experiment Station in cooperation with the Iowa Mutual Tornado Insurance Association and the Farmers' Mutual Reinsurance Association.

[2]Acknowledgment is made of the work done by Frank W. Peikert, Frank B. Lanham, William D. Test and Harold D. White, each of whom devoted at least a part of his graduate study to this problem.

RANK	ITEM	PERCENT OF TOTAL DAMAGE
1	Dwelling	46.7
2	Barn	20.5
3	Store	8.5
4	Elevator & Feed Mill	3.2
5	School	2.6
6	Comm. Building (Misc)	2.2
7	Church	1.7
8	Corn Crib & Granary	1.7
9	Amusement Place	1.4
10	Garage (Public)	1.3
11	Commercial Storage	1.1
12	Lumber Yard	0.9
13	Factory	0.9
14	Restaurant	0.8
15	Garage (Private)	0.8
16	Produce House	0.7
17	Miscellaneous	0.7
18	Machine Shed	0.5
19	Hog House	0.5
20	Office Building	0.5
21	Minor Outbuilding	0.4
22	Automobile	0.4
23	Bl'k. & Rpr. Shop	0.3
24	Hotel	0.3
25	Brooder House	0.3
26	Service Station	0.3
27	Poultry House	0.3
28	Municipal Building	0.2
29	Crops - Growing	0.2
30	Hay & Straw	0.1

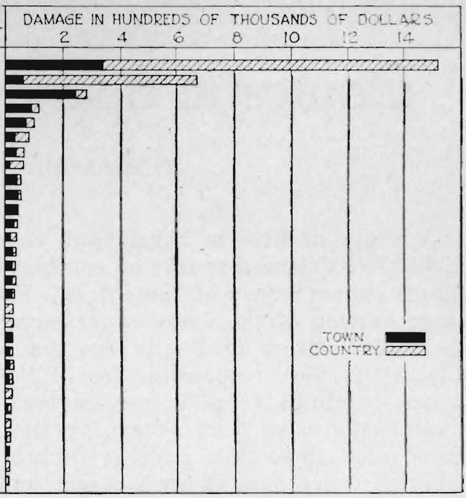


Fig. 1. Rural fire damage by item. Yearly average (1930-39).

RANK	CAUSE	PERCENT OF TOTAL DAMAGE
1	Defective flues	32.2
2	Sparks on roof	31.2
3	Defect. heat. sys.	8.1
4	Defect. wiring	8.0
5	Defect. oil & gas stove	5.6
6	Adjoining	2.8
7	Gasoline & kero.	1.9
8	Miscellaneous	1.4
9	Lightning (unrodded)	1.3
10	Candle, lamp, lant.	1.1
11	Incendiary	0.8
12	Spon. ign. dust-rags	0.7
13	Bonfire & rubbish	0.7
14	Sparks - engine	0.6
15	Matches	0.5
16	Lightning (rodded)	0.5
17	Smoking	0.4
18	Brooder lamp or stove	0.4
19	Spon. ign. of coal	0.3
20	Clothing near fire	0.2
21	Spon. ign. of hay	0.2
22	Elect. appliances	0.2
23	Children matches	0.2
24	Ashes etc. on wood	0.2
25	Spon. ign. of grain	0.1
26	Thawing water pipes	0.1
27	Smoking meat.	0.1
28	Blow & oil torch	0.1
29	Automobile	0.1
30	Water heater	0.0

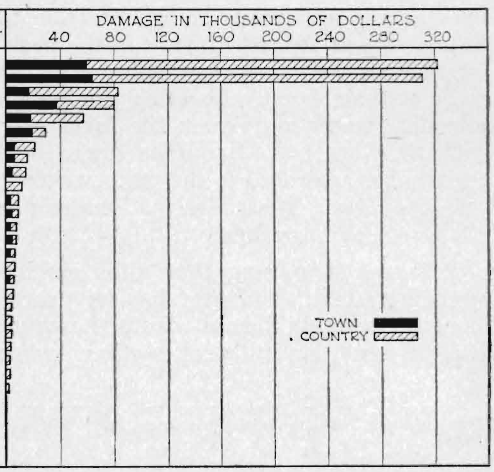


Fig. 2. Rural dwelling fire damage from known cause. Yearly average (1930-39).

disastrous grass fires or tractors operating close to dry and highly combustible straw have been equipped with spark arresters.

Application to residences has been somewhat more recent. An examination of "The Official Gazette of the United States Patent Office" shows that numerous patents have been granted on domestic spark arresters of varying designs.

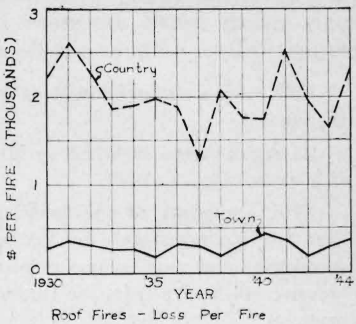


Fig. 3. Roof fires—loss per fire.

The use of a spark arrester is at best an attempt to remedy a bad situation. Sparks are formed when soot which has collected on a chimney wall becomes ignited and, burning violently, becomes disengaged and is carried out. If high grade fuels were always used or if the heating systems were of good design and carefully installed, the deposit of soot would be eliminated or at least greatly lessened. Poor firing methods, such as irregularity and improper placing of fuel, add to the hazard.

The National Fire Protection Association (8) has reported results of tests conducted to determine the combustibility of roofing materials when exposed to burning brands. However, burning brands are essentially different from incandescent soot particles. Soot particles will not flame when heated as will brands.

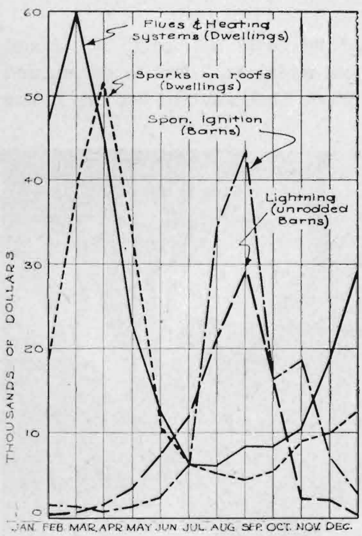


Fig. 4. Country fire damage from four major causes by month of occurrence. Yearly average (1930-44).

Ignition usually occurs on combustible roofing materials, but accumulated debris such as leaves and twigs in roof valleys may be ignited and cause a fire in materials usually considered to be fire resisting.

Domestic spark arresters have been used rather extensively in some communities with varying success. Several large insurance companies have for years insisted on their use on chimneys of buildings roofed with weathered wood shingles. Numerous unsatisfactory experiences have, however, been reported. Conditions in domestic chimneys vary considerably from those in industrial chimneys. Without forced draft and with low chimneys the natural draft is often inadequate without the addition of any apparatus which might interfere with it still further.

The following extracts from letters written to the Farmers Mutual Reinsurance Association by secretaries of county mutuals using spark arresters illustrate these difficulties rather emphatically. Others could be added to the list.

"We have a different kind of damage to report than any we have had heretofore.

"A spark screen installed by Mr. Frick became clogged one night about 8 o'clock, Jan. 3, 1936.

"The occupants of the dwelling did not know what was the matter, but tried to investigate by taking down part of the furnace pipe when the smoke and soot became unbearable. They had to open the house and remove all the fire from the furnace before they could stop the smoke and soot.

"They worked till the middle of the night and were in danger of their lives. Everything was covered with soot and smoke. You know how it clings to everything.

"Early in the morning they called for someone to get up on top the roof and examine the chimney, and they found the spark screen completely clogged by soot.

"The woodwork has to be repainted and everything cleaned up."

"About 8 o'clock we smelled smoke, and could not locate it. About 10 the house was filled with it, and about midnight, I had to get up and take the fire out of the furnace. Of course that was not bad, as it was

Fig. 5. Many fires are caused by chimney sparks falling on combustible roofs.

Fig. 6. Country fires usually burn to exhaustion.

only 22 below and storming to beat ————. The next morning, when we could see, we found (as I expected) the hen nest on the furnace flue was chuck up tight. Then all we had to do, was to get up, and cut the darn thing off. The wind was hitting it off I think at about 150 mi. per."

"However, we have some discouraging experiences brought to our attention just recently. One of our directors went to see about a small fire damage and he found that it was due to the spark arrester becoming clogged so that the pipe and chimney were filled with soot. The heat from the chimney, which was trying to burn out, evidently, scorched the wall paper and smoke soiled the room. The damage is not great but the feeling against spark arresters is not favorable. When the spark arrester was removed the soot went up in the air many feet and the damage inside the house was stopped.

"One of our directors bought the arresters for chimneys on his farm house. One became so clogged that the son had to take it off and clean the chimney before he could have a fire that would not smoke them out. The very same experience was suffered by the son of another of our directors who had paid for an arrester for the son's chimney. He had to get out on the roof in zero weather and remove the arrester so that he could have a fire without being smoked out."

The first spark arresters were made of very fine wire mesh. Because of clogging difficulties encountered, later models were provided with openings in the side walls. The completely enclosed arrester constructed of medium large mesh appeared somewhat later, stressing safety as the foremost consideration in design. Recently several arresters of the open top style with no openings in the side walls have been placed on the market. The top opening is in all cases protected by a baffle.

The committee on manufacturing hazards of The National Fire Protection Association (7) has set up a tentative standard for the design, construction and installation of domestic spark arresters. The standards as set forth below have resulted in much discussion and will, no doubt, have a tendency to bring about standardization of the design and construction of the domestic spark arrester.

DOMESTIC SPARK ARRESTERS

For Use on Dwelling House Chimneys, and Other Small Chimneys and Stacks

"7. The preceding General Rules (Section 1) shall apply and in addition the following:

"8. SIZE OF ARRESTERS

(a) The gross area of the surface of the arrester above the top of the chimney shall not be less than two times the net area of the chimney outlet.

(b) Arresters shall have vertical sides, at least in part, extending upward not less than 9 inches and on a line not within the flue area, except that arresters for rubbish burners need not comply with this rule.

"9. MATERIAL

(a) Arresters shall be made of copper bearing steel (0.25 of 1 percent copper) or of a metal equivalent thereto in strength, corrosion resistance and quality.

(b) All bolts, rivets or screws used in the assembly shall be made of copper, copper bearing steel or the equivalent thereof as regards strength, corrosion resistance and quality.

Note: Assembling by welding or spot welding is recommended to avoid rivets, bolts and screws.

(c) The minimum sizes of wire used for wire mesh arresters of this class shall be not smaller than .080 inch in diameter before coating; for arresters made of sheet metal or expanded metal the thickness of the metal, before coating, shall be not less than .0375 inch.

Note: .080 in. is equivalent to No. 14 W. & M. gauge.
.0375 in. is equivalent to No. 20 U. S. gauge. As the trade allows a variation of 2½% over and under the grade such variation in sheet and expanded metal is permissible.

(d) Unless built of metals, or their equivalent, mentioned in the 'Note' under Section 3 (a) all parts of arresters of this class shall be protected after fabrication by a corrosion resisting coating of one of the following forms or a coating equivalent thereto in abrasive and corrosive resistance.

1. A vitreous enamel coating applied in two separate coats, the first coating being fused before the second is applied.

2. A heavy hot dipped galvanizing. Hot dipped galvanized screening is acceptable if the galvanizing is applied to the fabric after weaving; arresters built of uncoated material shall be galvanized after complete assembling.

3. A heavy coating of cadmium plate or other equivalent plating applied after complete assembly of the arrester.

"10. SIZE OF MESH OR OPENINGS IN SCREEN

(a) No openings in the outer screens are to be larger than to pass a 5/8-inch sphere after screens are finished and coated, nor smaller than to pass a 5/16-inch sphere. (1/16-in. variance is allowed for in measuring.)

(b) Open top arresters do not qualify under these rules but adequately baffled openings in top or sides are acceptable provided that they do not permit the discharge of burning brands larger than those which would otherwise pass out of the arrester.

"11. MOUNTING

(a) The manufacturer shall furnish with each arrester of this class wires or their equivalent for securely fastening the arrester in place on the chimney or stack to prevent movement. Wires shall be of copper or of copper bearing steel galvanized or plated or the equivalent thereto. If of copper the mounting wires shall be not smaller than .080 in. diameter (14 W. and M. gauge); if of steel as specified above, wires shall be not less than .105 in. diameter (12 W. and M. gauge).

Note: Manufacturers of arresters should be required to furnish adequate instructions for mounting arresters in place.

"12. MAINTENANCE

Domestic arresters made under these specifications should last several years under normal conditions. Arresters should be kept adjusted in position. When worn to the extent that openings develop larger than the normal screen openings the entire arrester should be replaced with a new one."

These specifications are rather general in character, have largely to do with quality of materials and may or may not limit production to effective types. It would appear desirable to list the requirements of a good arrester and then to attempt to provide for such requirements.

Without question the primary requirement is that it effectively prevent the escape from the chimney of sparks large enough to be potential sources of ignition. This may at first appear obvious, and patent office records indicate that the same opinion was held by early inventors.

When low grade fuels are used, or the heating system is not of best design, however, provision must be made for a minimum interference with draft should the device become soot clogged. Under certain conditions partial clogging may result from frost accumulation or from wet snow. If possible, the device should resist clogging or admit of easy cleaning. Patents have been issued on self-cleaning devices.

Cost is an important factor. The public generally is not yet sufficiently convinced of the desirability of spark arresters to be willing to pay much for them.

Spark arresters should admit of easy installation and present at least a reasonably good appearance.

An analysis of the spark arrester problem brings to light five means which may be employed to do away with sparks or to remove them from the gas stream before it leaves the chimney.

1. If the chimney is kept clean, it appears improbable that dangerous sized incandescent soot particles will be formed. Cleaning may be done mechanically with brushes or by lowering weighted burlap bags down the chimney from the top. The difficulties and inconvenience involved usually result in no action being taken. Certain chemical means such as the introduction of sodium chloride (common salt) or zinc into the fire box have been proposed. Little is known of the

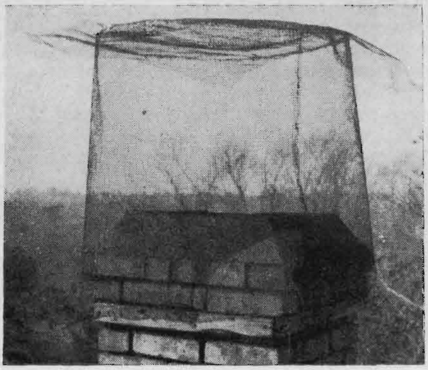


Fig. 7. A homemade spark arrester.

Fig. 8. Arrester No. 38. Pat. No. 2133506. Oct. 18, 1938.

effectiveness of these expedients, although some investigational work is reported later in this manuscript.

2. Early arresters were made of complete enclosures of comparatively fine mesh screen. For effectiveness this is undoubtedly the ideal, as sparks large enough to cause ignition cannot escape. It fails on Iowa chimneys, however, because in many cases sufficient soot will accumulate in a very short time to clog the arrester and cause smoke damage. At best the wire occupies so much space that the arrester must be large if it is to permit a sufficiently large free opening. A sleet or heavy wet snow will stop the arrester as effectively as the accumulation of soot. Early arresters used mesh as fine as that customarily employed for fly screen. In an attempt to overcome the clogging difficulty, the mesh size was successively increased to 4 to 1 inch, 3 to 1 inch and finally 2 mesh only to the inch, which was common at the time of the beginning of the investigations herein reported. Finding that soot particles with low density and specific heat must be large to cause ignition, the size was later increased in further attempts to stop clogging. This expedient alone seems futile, however, as even 1.5 inch mesh screen, too large to offer appreciable protection, may clog under extreme circumstances.

3. Soot particles are exceedingly fragile. It appears possible to utilize means of breaking the larger pieces into ones too small to do damage.

4. Spark arresters for industrial chimneys and stacks have successfully employed what may be termed the "air cleaner" principle. The gas is caused to change direction quickly, thereby projecting solid and heavy particles into a pocket out of the air stream. This method has been ineffective for residences; first, because the low-density sparks are not

easily disposed of in this manner but tend rather to follow the gas stream; and second, because so little energy is available to cause flow in the chimney that any interference may result in smoke damage in the house.

5. It is a well known principle in hydraulics that the transporting power of a fluid varies as the sixth power of its velocity. That is, if a stream capable of carrying a 1-ounce stone is doubled in velocity, it can move stones weighing 4 pounds. Likewise, if its velocity were cut in half, its transporting power would be so reduced that gravel weighing only 1/64 ounce could be moved.
   While flue temperatures involving changes in density modify this somewhat, it still seems to offer an effective means of disposing of the few rather large soot particles which may be loosened and travel out the chimney top.

With these conditions in mind, various tests have been made in order to determine the situations encountered and the ability of various types of spark arresters to perform. Details of apparatus, tests and results accompany each item later.

In general, the investigations attempted to determine:

1. Source of sparks causing roof fires.
2. Physical properties of chimney sparks.
3. Size of sparks necessary for ignition of wooden shingle roofs.
4. The susceptibility of various spark arresters to clogging.
5. The effects of a clogged arrester on air currents in chimney.
6. The effectiveness of the several spark arresters on the market at the present time in the retention and breaking up of soot particles.
7. The characteristics and behavior of rising gas columns in chimneys.
8. The design of an improved arrester which might overcome the difficulties found in others.

SOURCE AND CHARACTER OF SPARKS

This study was conducted to determine whether sparks from the fire box passing directly up the chimney are responsible for part of the roof fires or whether these sparks originate in soot deposits on the chimney walls.

An attempt was made to duplicate conditions found in the average dwelling. The set-up consisted of a New Vulcan heating stove with a stove pipe entering a brick chimney 6.5 feet above the floor. The chimney was 19′ 8″ high and extended 3 feet above a flat roof. The lower portion was 6.5″ × 11″ inside enlarging to 9″ × 13″ for the upper 2′ 6″.

The following fuels were burned separately: West Virginia coal, Illinois coal, Iowa coal, kindling wood, corncobs and paper.

The work was conducted at night, and a run of an hour made for each fuel with small quantities being added at 10-minute intervals. To facilitate rapid burning, a two-blade 16-inch fan driven by a one-fourth h.p. motor was placed 15 inches in front of the lower opening of the stove. Observations were made from the roof to determine whether any live sparks left the chimney.

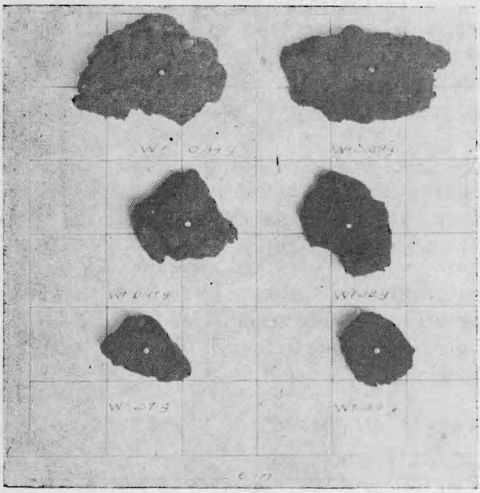


Fig. 9. Soot particles removed from a house chimney.

No live sparks were observed when the coal, wood or corncobs were used. There were occasional sparks from the paper fire but these floated off into the air rather than settling to the roof and lost all incandescence when only a few feet away from the chimney.

In these tests, any visible sparks had to originate from the stove as the chimney and stovepipe were clean of all soot. From this and other observations it is believed that roof fires are caused not by embers coming directly from the fire box, but by incandescent, flaky particles spalling from the inside of the chimney wall. This material is ignited and released by the heat of a large fire.

A number of chimneys were examined, some of which had been reported to have "burned out." On one occasion, the nature of the particles could be observed as they were being carried out by the flue gases. The fuel used was primarily Iowa coal with some wood and corncobs.

As the soot was removed from the chimney it broke up into rather flaky, irregular shaped fragments of varying sizes up to about 3 square inches in cross-section. A sample of these is shown in fig. 9. In all cases they were noted to be fragile when cold and more so when heated.

A large number of separate fragments were weighed and measured. Results are shown in table 1. The measurements are only approximations since the particles were quite irregular

TABLE 1. RELATIONSHIP OF SIZE TO WEIGHT OF SOOT PARTICLES.

No. of samples	Wt. milligrams	Av. size sq. in.	Square root of area (in.)
26	.020	0.25	0.50
19	.030	0.43	0.66
23	.040	0.55	0.75
17	.050	0.61	0.77
27	.060	0.72	0.85
28	.070	0.88	0.94
15	.080	1.07	1.03
21	.090	1.12	1.06
19	.100	1.22	1.10
11	.110	1.26	1.12
16	.130	1.49	1.22
1	.220	1.88	1.26
1	.390	3.06	1.75
1	.440	3.24	1.80
1	.580	3.75	1.94
1	.750	5.00	2.24

in shape. The particles ranged from about 1/4 to 3/4 inch in thickness.

Further work was carried out in an attempt to determine the density of various particles. The soot particles were placed on paper and the outline of each traced by a pencil. The area of the traced figure was determined by planimeter. The average height of the several particles was estimated, and all particles were weighed.

The 140 samples collected at random for this test were divided readily into two groups. Those of the first group were light and fragile as compared with those of the second group, which were heavy and dense. The particles found in the second group appeared to have been at one time in a molten state and solidified into various odd shapes and patterns. The more dense particles were secured from heating plants where wood was used for fuel, while lighter particles were taken from coal heating units.

Table 2 shows the steps followed in determining the density of the particles. Ten representative particles were selected for the table.

Only five particles examined could not be readily placed by

TABLE 2. DENSITY CALCULATIONS FOR 10 REPRESENTATIVE SOOT PARTICLES.

Av. area sq. cm.	Av. ht. cm.	Volume cu. cm.	Wt. gr.	Gr. density cu. cm.
64.52	1.27	81.90	10.00	0.121
159.30	1.27	202.10	11.20	0.055
58.10	2.54	147.90	10.50	0.071
73.55	2.54	187.00	12.30	0.066
67.75	1.91	129.00	12.20	0.088
15.81	1.91	30.19	12.55	0.416
12.28	2.28	28.05	13.60	0.485
18.09	2.28	41.30	16.70	0.405
25.80	1.27	32.79	17.65	0.540
34.82	2.54	88.50	49.10	0.556

simple inspection into the high- or low-density groups. The densities were charted and are shown in fig. 10.

Two series of tests were made to determine the loss of weight due to heating the soot particles. In the first series 20 representative samples of the nine weights shown in fig. 11 from several chimneys were heated 6 seconds for every tenth of a gram in weight. A Bunsen burner used for this purpose was kept to the same flame height for all the work. The average loss of weight was determined and found to be 50.4 percent, and the ratio of original to final weights was plotted.

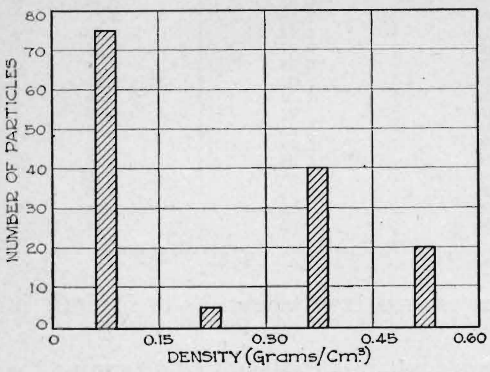


Fig. 10. Density of soot particles.

Another series of tests was carried out on weight-heat relationships of both low-density and high-density particles. The soot particles of low density were first examined as to their reaction to heat. The specimens were placed on a wire gauze and a Bunsen burner flame applied directly. These particles also were heated uniformly for a period of 6 seconds per 0.1 gram of weight. In the lower density group a total of 72 particles of 18 different weights were heated. The larger soot particles were not heated because difficulty was experienced in distributing the heat uniformly without disintegrating the mass. The average loss of weight of the particles examined in this series was 48.23 percent. The results are shown in fig. 11.

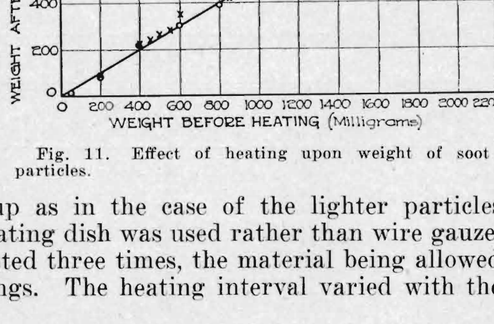


Fig. 11. Effect of heating upon weight of soot particles.

The same procedure was used with the high-density group as in the case of the lighter particles except that an evaporating dish was used rather than wire gauze. Each particle was heated three times, the material being allowed to cool between heatings. The heating interval varied with the original weight.

TABLE 3. THE LOSS FROM HEATING SOOT PARTICLES IN THE HIGH-DENSITY GROUP.
(Weights in grams)

Before heating	After heating				Max. % loss
	1st	2nd	3rd	Time of each heating (sec.)	
6.4	6.3	6.3	6.3	64	1.56
13.7	13.2	13.1	13.1	137	4.38
20.8	20.5	20.3	20.3	208	2.40
24.7	24.2	24.1	24.1	247	2.43
25.2	25.0	24.9	24.9	252	1.19
49.0	48.8	48.8	48.8	490	0.408

The heavier particles soon melted under the action of heat. When a flame was passed over the molten material, a flash occurred although the substance did not burn, as the ignition point was higher than the temperature caused by the Bunsen burner. The results of 33 samples examined were all very similar, and table 3 shows only typical weight reductions. The losses were small compared to those of the particles in the low-density group.

REMOVAL OF SOOT FROM CHIMNEY WALLS

One test was made of a method frequently proposed for removing the soot from the chimney wall. The laboratory stove and chimney, as previously described, were utilized for the test. Iowa coal was used for fuel, and burning was continuous for 3 days. At the end of this period about $\frac{1}{8}$ inch of fleecy soot deposit was uniformly distributed along the periphery of the stovepipe and the inside of the chimney walls.

With the stove at a red heat seven zinc fruit jar caps were placed in the fire box.

At the time the zinc was thrown into the stove a characteristic black coal smoke was issuing from the flue. After a period of 2 minutes had elapsed, a white smoke was arising from the chimney top. At the end of 4 minutes a noticeable flow of soot was evident, and this continued for approximately 2 minutes. No flames or other signs of burning within the chimney could be observed. The velocity of the chimney gases was apparently increased somewhat. The white smoke continued to emerge from the chimney for a period of 25 minutes.

An examination after the test had been concluded showed the sides of the firepot and the chimney to be lined with a white crystalline material.

Although the soot was not entirely gone, the deposit had been very definitely decreased. Inspection showed that more soot had left the stovepipe and chimney than had appeared to escape the flue in the solid form.

The reaction of oxidizing zinc is exothermic, 84,600 calories of heat being given off by each gram molecular weight of the metal oxidized. The carbon on the inside of the heating plant being subjected to this heat is oxidized and passes from the flue as the oxide.

Fig. 12. Cleaning soot from a chimney with zinc. Top: Appearance 2 minutes after placing zinc in fire box. Bottom: Appearance 23 minutes later.

CLOGGING OF SPARK ARRESTERS

Under certain conditions clogging has been so excessive as to resist the natural flow of gases in the chimney. Several tests were made to determine the rapidity with which this clogging took place, both by using arresters on a chimney and by placing different screen samples within a chimney. The set-up was the same as described under "source and character of sparks" (p. 185).

The first portion of the test consisted of a comparison of the clogging tendencies of several sizes of galvanized wire mesh. The screen was cut to fit snugly on the inside of the chimney and was suspended on wires 12 inches from the top of the flue. In this manner the effect of wind on the rate of sooting was made negligible. Conditions throughout the test were maintained as favorable as possible to the formation of soot, and an effort was made to produce the maximum amount of smoke at all times.

The first test was made with screen having three meshes to the linear inch. The fuel consisted of freshly cut green elm wood, and burning was carried on continuously for 64 hours. The maximum sooting obtained closed only 20 percent of the area of the meshes. The test was concluded when a dashing rain washed the screen clean of any soot deposit.

The deposit on the screen was light brown in color, of grainy structure, exhibited slightly oily tendencies and fell readily from the screen when jarred or exposed to wind. Other than to show the nature of the soot deposit the test showed but little as to the susceptibility of the screen to clogging.

The testing was continued using a fuel charge consisting of equal parts by weight of green elm wood and Iowa coal. After 14 hours of continuous burning the screen was uniformly covered on the top side with about 1/16 inch of soot, rendering the wire invisible. Likewise on the underside the meshes could not be seen, since the soot was hanging down from the wires in small cone-shaped deposits.

By adding Iowa coal to the fuel charge the rate of sooting was increased greatly, complete obstruction being noted after 14 hours. The collected soot deposit was black and fine-textured and not as fragile as that from wood alone.

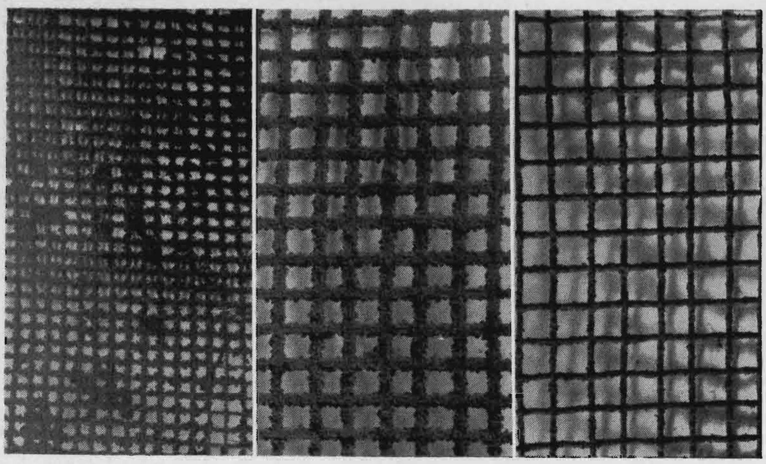
This test was repeated using only Iowa coal as a fuel. The amount of clogging as shown in fig. 13A resulted after 20 hours. It can be seen that complete obstruction occurred in some areas.

A second test was made using a two-mesh-to-the-inch screen and a fuel charge of green elm wood and Iowa coal in equal proportions by weight. Complete obstruction was observed after 17 hours of continuous burning. As might be expected the soot deposit on the top of the screen, although uniform, was not as heavy as in the case of the No. 3 mesh screen. The cones of soot formed on the bottom of the screen were not as long as in the case of the smaller mesh.

A third test was made with a ¾-inch mesh. Using the same fuel proportions and procedure, burning was carried on continuously for 58 hours. The soot deposit was uneven with a maximum deposit near the center of the screen where several meshes were about 70 percent closed.

This test was repeated using only Iowa coal as a fuel charge. After 90 hours of burning the screen openings were reduced between 50 and 60 percent. Two light rains during this period did not remove any large amount of the deposit. The condition of this screen at the completion of the test is shown in fig. 13B.

After being taken from the chimney, this screen was placed first in a 6- and then in a 12-mile-per-hour wind for 3-minute periods. The 6-mile wind had little effect, but the 12-mile wind



A B C

Fig. 13. Sooting of wire mesh. A—3 mesh screen. B—¾-inch mesh clogged. C—¾-inch mesh cleaned by the wind.

carried out the deposit almost immediately, leaving the screen practically clean.

At the end of a fourth test, using a 1-inch mesh screen 90 hours with Iowa coal as a fuel, a considerable soot deposit was noticed, but it dropped out in the process of removal due to slight jarring. A certain amount of soot deposit can be expected for both large and small mesh screen, but it is more easily removed by the wind from the larger size mesh.

The work on the clogging of the various sizes of mesh screen was followed by tests of arresters in an attempt to determine the rate at which the clogging takes place.

Arrester No. 21 (see page 210) was first placed on the chimney; Iowa coal was used as a fuel. A considerable coating of soot was noticeable by the third day; this increased up to the eighth day when a very strong wind blew out most of the deposit. Part of the openings were reduced by as much as 40 percent. This was especially true on the side opposite the direction of the prevailing wind.

Arrester No. 13 was also tested, using Iowa coal as a fuel charge. The period of this test ranged over 203 hours of actual burning. The weather ranged from warm calm days to some that were rather cold and windy. The greatest amount of clogging, occurring near the bottom of the arrester, reduced the free openings in the ¾-inch mesh about 50 percent. The reduction in the inch mesh was practically negligible. Observations were made three times daily.

The deposition of soot does not proceed at a uniform rate. The fuel, method of firing and weather all have their influences, the latter being the greatest factor. The draft in the stove is affected by the outside temperature which in turn influences the fire. On warm, calm days the draft is reduced, and more unburned fuel particles leave the flue as smoke, causing rapid clogging. Rain or wind helps to remove part of the deposit already formed. The collection of soot is rather light and fragile, and therefore the wind is very helpful in keeping this removed.

A third test was made using arrester No. 42. The fuel charge for this test consisted of green elm wood and Iowa coal in equal proportions by weight. Burning was continuous for 430 hours, after which period a hard dashing rain washed the arrester clean.

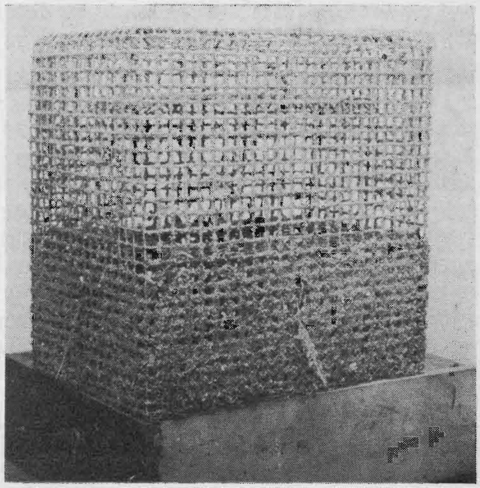


Fig. 14. Artificially clogged arrester.

Difficulty was experienced in approaching actual conditions in the laboratory because of the varied fuels used by the farmer, differences in weather and other highly variable factors.

Laboratory and field experience indicated the impracticality of using for experimental purposes arresters which had been clogged under actual field conditions. After observing actual clogging in the field, an effort was made to approach the nature of this clogging in the laboratory by artificial means. Using a mixture of casein glue, sawdust and fine sand, the meshes of each arrester were filled as illustrated in fig. 14.

Iowa coal was used for fuel in the stove. Special effort was made to produce heavy black smoke.

As the smoke issued from the flue, each arrester in an artificially clogged condition was placed on the chimney top. When a noticeable wind was in evidence the smoke would not pass readily through the clogged meshes of the arrester. In the arresters having no free openings the smoke sought the larger mesh openings. In the open top style of arrester and those having free body openings the smoke followed the path to the openings.

IGNITION OF WOOD SHINGLES BY INCANDESCENT SOOT PARTICLES

Since the chief function of a spark arrester is to pass only soot particles so small as not to cause a fire when falling on a combustible roof, one of the important parts of this work was to determine the maximum allowable size of mesh for use in a spark arrester. As difficulty with clogging is increased if the meshes of the arrester are small, it is desirable to use a mesh as large as possible.

Two series of tests were made to determine how large a mesh could be used without danger to various types and conditions of combustible roof coverings.

For the first test, red cedar shingles in three ages or conditions were used, and sections of roof 24 by 28 inches were constructed from each with the shingles laid 4½ inches to the weather. The roof deck was made from 1 by 4 inch sheathing spaced 4 inches on centers. The first section was made with old, very dry shingles, badly weathered and rather loose and curled in many cases. This was intended to approach the worst condition in which dwelling roofs would probably be found. The second section represented old shingles in fair to good condition as would be found on an old roof considered in good repair. The third included sections made from No. 1 grade new red cedar shingles.

Each roof section was set at a one-fourth pitch. Electric fans furnished a 3-mile-per-hour wind. Samples of soot were weighed and heated in the manner explained previously. These were then dropped on the roof as near as possible between the shingles. If at the end of 3 minutes the wood blazed, the sample was considered as causing ignition. This procedure was repeated for various sizes of soot samples, weighed before heating, until the minimum weight sample was found below which ignition did not occur and up to the size causing 100-percent ignition. Separate chunks of soot were used as much as possible, but the larger samples were made up from a number of fragments. These were deposited on the roof to a depth of ½

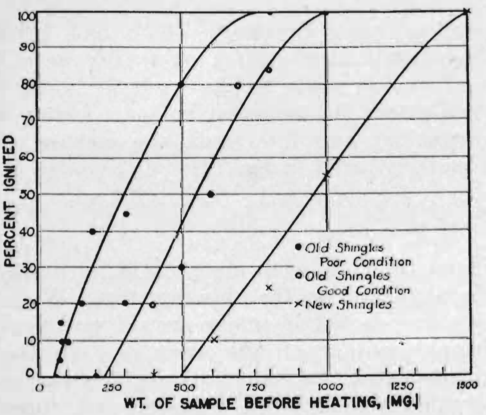


Fig. 15. Size of brand required to ignite wood shingles.

TABLE 4. NUMBER OF SOOT PARTICLES CAUSING IGNITION.

FIRST SERIES

Wt. mg. heated		Ignition					
		New shingles		Old shingles			
				Good condition		Poor condition	
Before	After	No.	%	No.	%	No.	%
60	30	...	...	...	...	0	0
70	30	...	...	...	...	3	15
80	40	...	...	...	...	1	5
90	45	...	...	...	...	2	10
100	50	...	...	...	...	2	10
150	75	...	...	...	...	4	20
200	100	...	...	0	0	8	40
300	150	...	...	4	20	9	45
400	200	0	0	4	20	...	...
500	250	...	...	6	30	16	80
600	300	2	10	10	50	...	...
700	350	...	...	16	80	...	...
800	400	5	25	17	85	20	100
1000	500	11	55	20	100	...	...
1500	740	20	100	...	...	...	...
2000	990	20	100	...	...	...	...

Each value given represents 20 trials.

SECOND SERIES

Wt. range of particles (mg.)	Roof sections								
	1			2			3		
	O	C	I	O	C	I	O	C	I
126- 200	..	..	..	..	..	..	11	4	0
201- 300	..	..	..	9	1	0	10	10	0
301- 400	..	..	..	18	2	0	5	15	0
401- 500	13	2	0	14	6	0	0	8	12
501- 600	15	5	0	2	18	0	..	..	..
601- 700	14	6	0	0	14	6	..	..	..
701- 800	9	11	0	0	0	20	..	..	..
801- 900	0	20	0	..	..	..	..	..	..
901-1000	0	20	0	..	..	..	..	..	..
2426-2500	0	13	2	..	..	..	..	..	..

Numbers indicate particles involved.
O—No visible effect.
C—Charring.
I—Ignition.

inch so as to approach one large piece as far as possible. The results are shown in table 4 and fig. 15.

1. New Shingles. It is very unlikely that sparks are a prevalent cause of fires to a new roof or one in very good condition. It was impossible to get single soot particles of sufficient size for these tests as it would require a chunk about 2 inches square and ¾ inch thick to cause ignition under such conditions.

2. Old Shingles in Good Condition. The results show that old shingles in good condition are not ignited by heated soot

particles less than about 100 to 150 milligrams in weight. This would be a fragment approximately 1¼ inches square.

3. Badly Weathered Shingles. The smallest size of brand causing ignition weighed 70 milligrams before heating. According to the work reported earlier in this publication, this would be a fragment about ¼ inch thick and having an area of approximately 0.88 square inch. This size could not pass through a ¾-inch mesh screen. A smaller brand apparently will not ignite shingles even under the ideal conditions that occurred in this setup.

The requirements placed upon a spark arrester should be to further break up or retain any live sparks more than 30 to 40 milligrams in weight. This allows a 50 percent reduction in weight to the soot by heating. Any smaller particles might be allowed to leave the chimney and thereby reduce the accumulation in the flue.

In actual practice the probability of ignition would be considerably less than shown by these results. In the first place, each sample was placed in the space between the shingles where the possibility of ignition was the greatest, especially on shingles badly weathered. Furthermore, all samples were heated and placed directly on the roof thereby bringing a hotter brand in contact with the wood than would usually be the case. The top of the chimney is ordinarily several feet above the roof; if a hot soot particle drops through this distance, considerable cooling will take place, especially with the smaller sizes.

Only particles of the low density group were used for these tests because they are the only ones which might be released from the chimney wall and pass out through the spark arrester. As heretofore explained, the specimens of the high density group melted when exposed to heat. They would simply run down the chimney wall and not be discharged.

The roof sections used during the second similar series of tests may be briefly described as follows:

Test No. 1. These shingles were laid new less than 2 years previously. The section secured was 3′ × 3′ 6″. All the shingles were lying flat, seemed firm and in good condition. The shingles were of red cedar, perhaps originally graded as No. 1. The individual shingle was 16″ in length, varying in thickness from 3/8″ at the butt end to 3/32″ at the other extremity, and laid about 4¾ inches to the weather. The average moisture content of the shingles during the test was 10 percent.

Test No. 2. The section was originally a cupola on a small storage structure. The base measured 4′ × 4′ and the height 1′ 8″. The shingles were of red cedar, 16″ in length and varying in thickness from ¼″ at the butt end to 3/32″ at the other extremity. They were of random widths and laid $5\frac{1}{8}''$ to the weather. They were not noticeably curled, although they were somewhat soft, having a slight mossy feeling. A definite impression could be made in the shingles with the fingernail. The age of the section was estimated to be about 15 years. The severe weathering which the shingles had undergone made it difficult to determine the grade, which was perhaps No. 2. The moisture content was determined by analysis to be 8 percent.

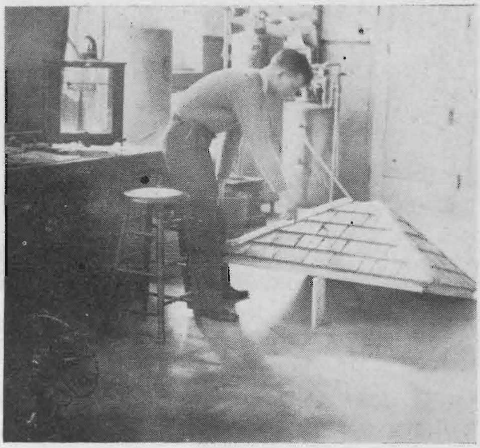


Fig. 16. Placing incandescent particles on roof deck.

Test No. 3. The section $4' \times 5'$ was cut out of an old grain storage building on the Agricultural Engineering Farm. The shingles were badly curled and cracked. The shingles, probably grade No. 2, were 16″ long, $\frac{1}{4}''$ thick at the butt end and diminishing to 3/32″ at the other extremity. The shingles were laid $5\frac{3}{4}''$ to the weather. The estimated age of the section was 30 years. An analysis showed the moisture content to be 9 percent.

Each roof section was set up at a one-fourth pitch. The soot samples were weighed into classes of 25 milligrams. Five samples were weighed out for each weight class per section tested. The particles were heated by a Bunsen burner with a flame divider attachment. The flame was kept uniform throughout the test. The particles were held in the flame by means of crucible tongs and heated 12 seconds for every 100 milligrams of weight. Method of applying the particle to the roof deck is shown in fig. 16.

A wind was maintained on the section by a suitable fan. Nine measurements were taken of the wind velocity perpendicular to the section, the average being 528 feet per minute, or 6 miles per hour.

The definition of ignition (I) as applied to these tests involved a plainly visible flame of growing proportions. Each particle was given full opportunity to ignite the roof by allowing the sample to remain on the section until all signs of incandescence had disappeared. Charring (C) was recorded if when the heated specimen was placed on the roof definite signs of burning appeared, accompanied by the formation of a glowing bed of coals

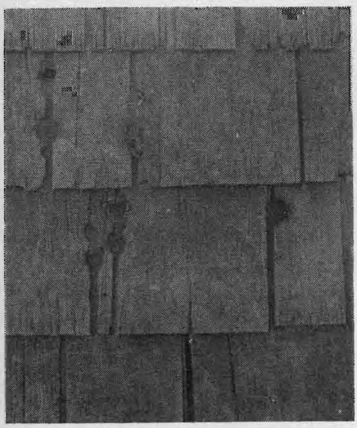


Fig. 17. Shingle roofs tested. Top left: Shingles 2 years old. Top right: Shingles 15 years old. Bottom: Shingles 30 years old.

which persisted for at least 3 minutes, but which later went out without any visible flame. The notation (·O) indicates that neither ignition nor charring took place.

Under the action of the wind the smaller specimens would often move about, causing charring in more than one spot. This did not take place, however, in the case of the particles sufficiently large to cause ignition. The heated samples were placed, where possible, between the shingles. This facilitated ignition, but since the particles could very easily alight in this spot under actual conditions, the procedure was not considered too severe. The time required for ignition, which began at the time the particle was placed on the roof and ended when a flame was first noticed, varied from 3 to 4 minutes for the poorer sections up to 30 minutes for the section having new shingles. The interval required for ignition varied inversely with the size of the particle. The room temperature was maintained at 76° F. throughout the tests.

When a heated specimen of sufficient size to cause ignition was placed on the roof, smoking began almost immediately. The burning area was soon visible, being glowing red under the action of the wind. Frequently when the bed of coals would reach a diameter of about 2 inches the burning had reached the under side of the section and a burst of flame would follow. Supported by the sizable bed of coals and aided by the wind, the flame would spread rapidly.

Table 4 indicates the results on the sections as specified in the headings. Figure 17 shows several views of the roof decks under test. Figure 18 shows the results of the ignition tests in graphic form.

The test was concluded without 100 percent ignition being secured on the shingles which were in good condition, for the following reasons:

1. A soot particle suitable for this test procedure weighing

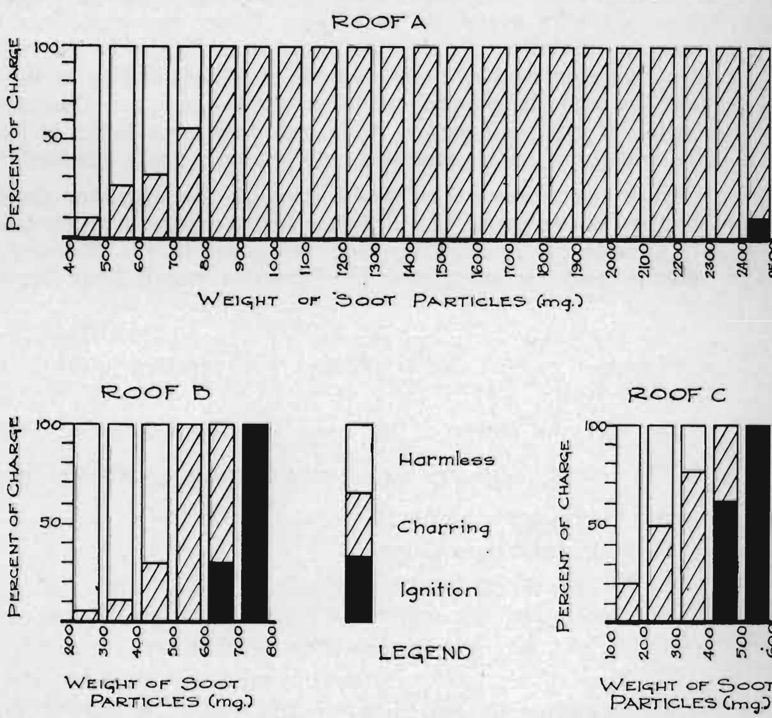


Fig. 18. Results of ignition tests.

above 2,500 milligrams is far too large to pass through any spark arrester on the market at the present time.

2. A sample weighing above the limits of the test would not likely be carried out by flue gases and hence would not alight on the roof as a result of a chimney burnout.

3. Particles weighing above 2,000 milligrams showed a marked tendency to break up into smaller particles when heated under the action of the burner for the period allotted.

The results of the test indicate that fires resulting from sparks alighting on a new wood shingle roof are very improbable.

Old shingles, even in apparently good condition, may be ignited by comparatively lightweight soot particles. The density is so low, however, that none of the dangerous particles could pass through a ¾-inch mesh screen.

CHARACTERISTICS OF RISING GAS COLUMNS IN CHIMNEYS

A study was made of the characteristics of rising gases in a house chimney in an effort to determine the probable maximum velocity which might be expected. Other investigations were made to determine the relation between a change in the velocity of a rising current of gases and the resulting ability to lift soot particles and the possibilities of using a sheet iron chimney extension of enlarged section, with and without a baffle, to reduce the velocity of such gases and thus act as a spark arrester.

Since the movement of gases through the ordinary dwelling chimney is the result of a difference of temperature between the air outside of the building and the gases in the chimney, the velocity may be calculated by formulas which have been developed (5).

The ability of a rising current of gases to lift particles of solid matter such as soot is affected by several variables in addition to velocity.

The carrying power of flue gases is influenced by:

I. The velocity of the rising current of gases, as affected by:

  A. Atmospheric temperature
  B. Flue gas temperature
  C. Barometric pressure
  D. Density of flue gas
  E. Height, size and cross-section of chimneys
  F. Type of connection between combustion chamber and flue
  G. Situation of the chimney with respect to higher objects nearby

H. Number of stoves or furnaces served by the chimney
I. Coefficient of friction of the chimney surface

II. Characteristics of the soot particles, as affected by:

A. Stoves or furnaces
1. Type of grate bars which influences the amount of gases produced
2. Location, size and effectiveness of dampers and draft doors and their control
3. General design characteristics of the stove or furnace

B. Fuels
1. Fuel ratio and moisture content of fuel used
2. Combustion characteristics
3. Size of lumps

C. Human factors
1. Method and frequency of charging the fire pot
2. Control of dampers and draft doors
3. General care of plant

Because of the effect of these variables the soot produced is itself a variable as to:

1. Size of particle
2. Shape of particle
3. Density
4. Coefficient of friction
5. Action upon the application of heat—loss of weight or change to molten state

Obviously, it would be next to impossible to investigate thoroughly all of these factors and their interrelationships for house chimneys. With this difficulty in mind, studies were made of the velocities necessary to carry out particles of dangerous size. Subsequent tests used ranges in velocities set by these experiences. Actual soot particles used in some preliminary tests were troublesome because of being so fragile and difficult to replace. It was found that the density of balsa wood was 150 mg. cm^3 and the density of cornstalk pith was 45 mg. cm^3. These represent averages for the soot particles which cause ignition of wood shingle roofs.

For this reason it is believed permissible to make copies of soot particles out of balsa wood and use them in the experimental work. For determination of the basic principles underlying the carrying power of a rising current of gases, three distinct shapes were used; spherical, cubical and flat. The weights in milligrams of the spherical specimens were 250, 400, 500, 700, 900, 1,000 and 3,000. The cubical particles weighed 120, 500, 2,830 and 9,850 milligrams. The flat particles weighed 180, 220, 300, 480, 710, 710 and 1,290 milligrams. The flat particles were made in odd shapes as much like representative soot particles as possible, and their surfaces were gouged and scarred to imitate actual soot specimens (fig. 19).

The apparatus used to provide the rising current of gases consisted of a grain blower with a blower wheel of 21-inch diameter, a section of sheet iron pipe 12 inches in diameter by 9 feet, 8 inches long and a 3 h.p. portable electric motor to drive the fan. The fan discharged upward and the pipe was mounted vertically over the opening. A screen of ⅜-inch mesh was placed in the pipe at a point 30 inches below the top to prevent any of the specimens from dropping down into the fan. The intake opening of the fan case was provided with a door which was adjustable from a position near the top of the pipe from which the actions of each specimen could be closely watched.

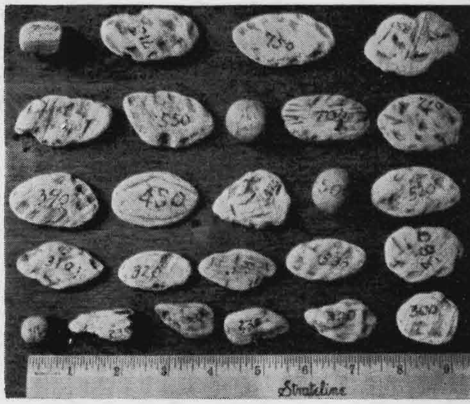


Fig. 19. Balsa wood particles.

In conducting the tests each specimen was placed on the screen in the pipe and the motor started with the door in the fan case closed. When the fan had gained its normal speed, the door was opened slowly until the specimen was barely lifted out of the pipe, at which point the door was clamped in position and the velocity of the air current determined.

In determining the velocity of the air in all tests with the round pipe, four readings were taken with a 4-inch vane type anemometer each time a specimen was expelled, all in a plane with the top of the pipe. One reading was taken in the center of the pipe and the other three at equally spaced intervals around the periphery of the pipe. Readings were weighted according to their influence upon the average. Results are shown in table 5 and charted in fig. 20.

The results of this experiment are at some variance with the hydraulic theory that the transporting power of a fluid varies as the sixth power of the velocity ($T = V^6$). The results obtained were for the spherical particles, $T = V^{6.91}$; for the cubical particles, $T = V^{6.87}$ and for the irregular particles, $T = V^{5.77}$. The variation may be due to effect of turbulence or to inability

TABLE 5. AIR VELOCITY REQUIRED TO EXPEL BALSA WOOD PARTICLES.

Test no.	Shape	Wt. mg.	No. trials	Air velocity ft./min. Min.	Max.	Av.
1	Sphere	245	5	1231	1275	1252
2		400	5	1252	1270	1261
3		440	12	1251	1429	1347
4		500	7	1258	1317	1291
5		700	5	1484	1512	1499
6		900	6	1387	1432	1413
7		1000	12	1476	1619	1537
8		3000	5	1708	1768	1746
9	Cube	117	3	767	790	781
10		497	3	958	983	967
11		2828	3	1117	1160	1131
12		9846	3	1508	1542	1524
13	Flat	175	5	464	501	485
14		220	5	447	482	465
15		300	6	561	595	584
16		300	5	638	677	657
17		480	5	586	606	595
18		710	5	637	679	659
19		710	5	672	747	713
20		1290	5	635	707	682

to make accurate observations of air velocity. Perhaps the important consideration here, however, is the fact that irregular particles of a given weight will be carried out of a chimney by a current of much lower velocity than that required to transport a sphere, approximately one-half the velocity in the case of those tested. The results also show that a slight variation in velocity results in a large variation in the size of particle transported.

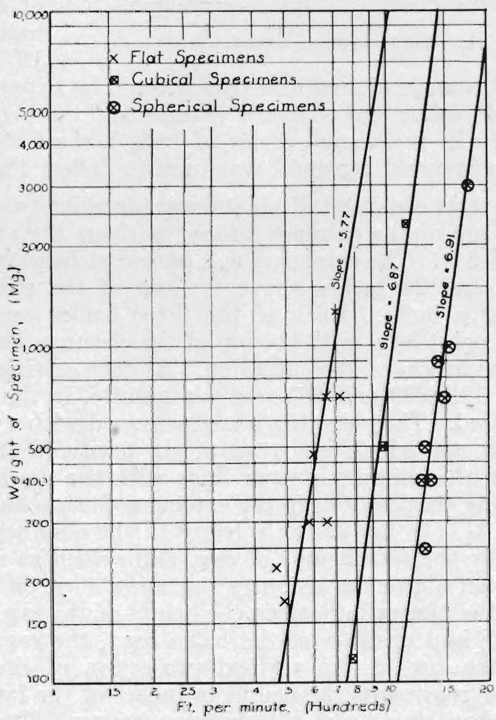


Fig. 20. Transporting power of air.

Considering the change in the transporting power of a fluid resulting from change in velocity, it seemed desirable to attempt to reduce the velocity of gases in a chimney by increasing its cross sectional area. If this could be done, the transporting power might be so reduced as to make practically impossible the exit of soot particles of dangerous size. This principle was employed successfully in the design of locomotive smoke stacks many years ago.

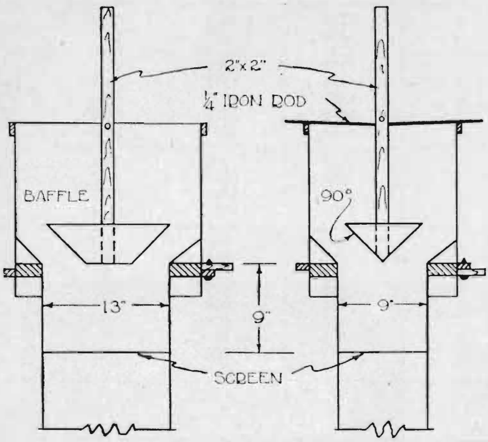


Fig. 21. Model chimney, extension and baffle.

A model chimney of galvanized sheet steel (fig. 21), whose inside dimensions were 9″ × 13″, was set over the grain blower previously mentioned. Around the top of the chimney a 2″ × 4″ collar was placed to represent the top course of brick of a chimney. An extension 16″ × 20″ of sheet steel was made of such size that it could be slipped down over the 2″ × 4″ collar and adjusted to any height above the collar up to 2 feet. In the second series of tests a sheet steel baffle shaped like an inverted pyramid was used to deflect the air currents.

The tests consisted of measuring the velocity of the air stream at the top of the chimney proper without the extension or baffle and with it. The extension was placed at heights of 12 inches, 18 inches and 24 inches above the top of the chimney, with and without a baffle. Each of the three baffles was tested with its lowest point level with the top of the chimney and also at a point half the height of the extension. At each setting, three velocities of air, 192, 399 and 862 feet per minute, in the chimney proper were used. The velocities were measured with a 4-inch vane-type anemometer which was read at six positions uniformly distributed in the chimney proper flush with the top and at the corresponding six positions in the extension flush with its top as shown in fig. 21. In fig. 22 the velocity in the chimney proper is indicated by the zero height of cap, and velocities at the top of the extension above the chimney top are shown on the vertical line above the figures indicating the height of the cap. In designating the size and position of the baffle used, the capital letter represents the size of the vertical projection of the baffle, and the number represents the height in inches of the lowest point of the baffle above the top of the chimney proper. That is, A indicates use of the smallest baffle, whose dimensions are 4″ × 7.85″, projected area equal to 31.40 square inches or 27 percent of the area of the chimney proper; B indicates use of the medium sized baffle whose dimensions are 6.16″ × 9.90″, projected area equal to 60.98 square inches or 52 percent of the area of the chimney proper, and C indicates use of the largest baffle whose dimensions are 9.00″ × 13.00″, projected area equal to 117.00 square inches or 100 percent of the area of the chimney proper. Figure 22 shows the change in average velocities resulting from changes in the height of the cap and the use of baffles.

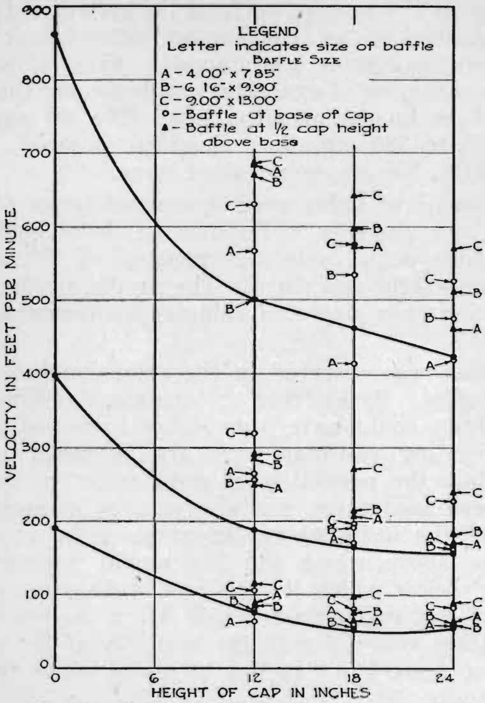


Fig. 22. Effect of various cap heights on velocity of air currents.

The maximum reading is perhaps more significant relative to the discharge of soot particles than is the average. The rectangular shape of the chimney and the abrupt change in size at the base of the extension tend to produce eddy currents and unequal velocities at various points in the cross section. Maximum velocities observed are also indicated in fig. 22.

The use of an extension did result in a decrease in both the average and maximum velocities observed.

The difference was more marked in the case of the lower flue velocities.

In the second part of this test the intake door in the fan case was set so that the velocity was 740 feet per minute, which approximates the maximum velocity expected in a chimney. A charge of 16 irregular, flat pieces of balsa wood representing soot particles was placed on a screen 9 inches below the top of the chimney proper. Eight of these specimens were lighter in weight than the figure, 375 mg., set by Lanham (7) as the smallest size of soot particle that may be termed dangerous, and eight were larger. There were one each weighing 175, 220, 230, 235, 285, 320, 410, 425, 490, 510, 550 and 575 milligrams, respectively, and two each weighing 300 and 480 milligrams.

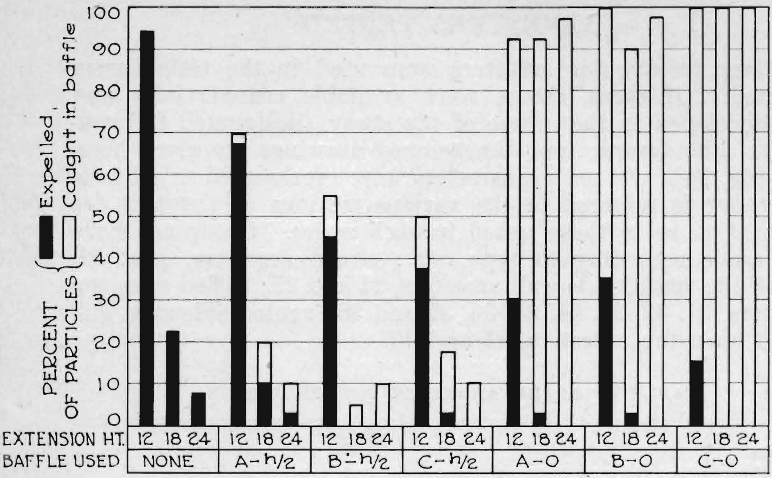
With the charge on the screen the blower was started and run for 1 minute in each trial. At the expiration of each 1-minute run the motor was shut off and the behavior of each specimen recorded as to whether it was expelled from the system, deposited in the baffle or remained in the extension and settled back down on the screen when the blower was stopped. Five trials were made with each combination of extension and baffle and the same combinations used as in the previous test. The 40 particles weighing from 175 to 320 mg. were classified as small, while those weighing 420 to 575 mg. were called large.

Although the density of balsa wood is representative of that of the dangerous soot particles, differences in their coefficients of friction may alter actual velocities required to lift a soot particle of the same weight and shape. The results are intended to show the behavior when sizes and chimney arrangements are changed.

Marked turbulence was observed in the extension both with and without the baffles. By shifting the anemometer somewhat the recorded readings could have been either increased or decreased. Corresponding readings were always taken at the same point to reduce the possibility of error from this source. When the baffle was used there was always a point along the wooden support of the baffle where the anemometer rotor remained stationary, above which the instrument registered a rising current and below which it registered a descending current. The point of rest varied from 1 inch below the top of the extension to 10 inches above it with the majority of the points falling in the group from 4 to 6 inches, inclusive, above the top of the extension.

Increases in the height of the extension proved to be beneficial in reducing the number of particles expelled. The number was further reduced by the use of baffles. Baffles placed low in the chimney were more effective than those placed higher.

The smallest baffle was most effective in reducing the average velocity, but less effective than either of the larger ones in preventing escape of soot particles. This point can be at least partially explained by the fact that the larger baffle causes a greater change of direction of the air stream and, in consequence, a greater turbulence of flow; this causes more of the specimens to be thrown over the baffle where the air has little lifting power, and as a result the particles are deposited in the baffle. The larger baffles also provide a larger place for the sparks to fall into.



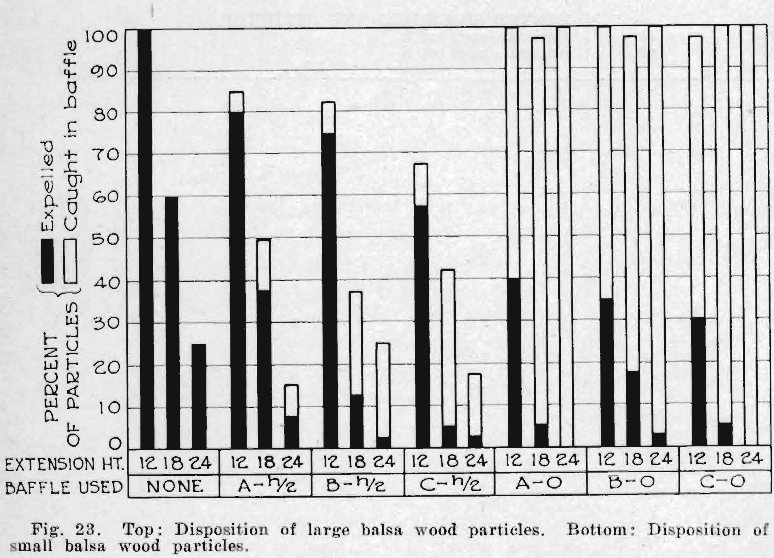


Fig. 23. Top: Disposition of large balsa wood particles. Bottom: Disposition of small balsa wood particles.

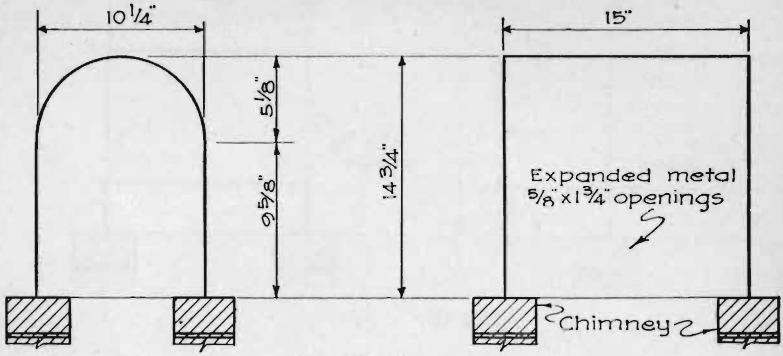
ARRESTERS TESTED

Fifteen rectangular arresters were used in the tests herein reported. Of these, eleven were available commercially and four developed in the course of the study (designated "Hawkeye"). Photographs and dimensioned drawings are given herewith (fig. 24). As not all arresters were represented in all tests the reader is referred to the various sections of the text for information as to those tested in each series. Groupings have been made according to type, viz.: closed arresters, Nos. 11, 12 and 13; vented side wall arresters, 21 and 22; baffled open top arresters, 31, 32, 33, 34, 35, 36, 37 and 38; vented sidewalls and baffled open top arresters, 41 and 42.

TABLE 6. SPARK ARRESTER IDENTIFICATION.

Free area	No.	
		CLOSED
0	11	Mullin
0	12	Security
0	13	Hawkeye—closed top
		VENTED SIDEWALLS
32	21	Pioneer
38	22	National—closed top
		OPEN TOP (baffled)
60	31	Peerless
28	32	National—open top—type C
35	33	Star—No. 1
35	34	Star—No. 2
44	35	Star—No. 2 (3 baffles)
44	36	Hawkeye—(hip baffle)
72	37	Hawkeye—(sheet baffle) No. 1
88	38	Hawkeye—(sheet baffle) No. 2
		VENTED SIDEWALLS AND OPEN TOP
70	41	National—open top A
74	42	National—open top B

Fig. 24. Spark arresters.



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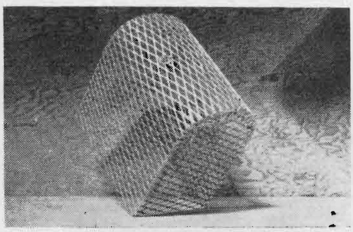
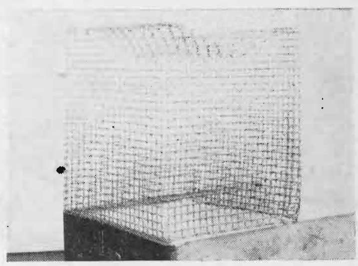
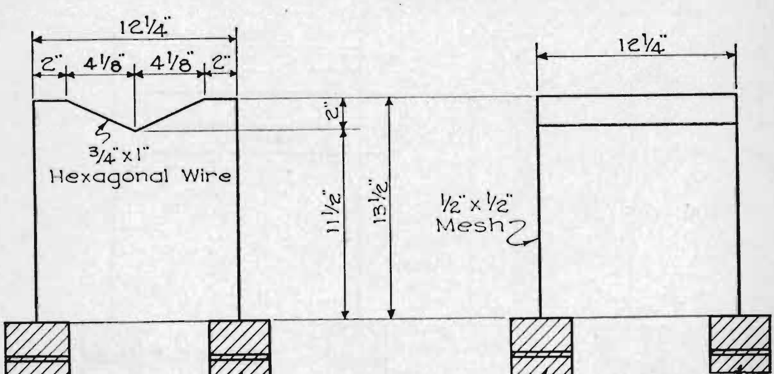
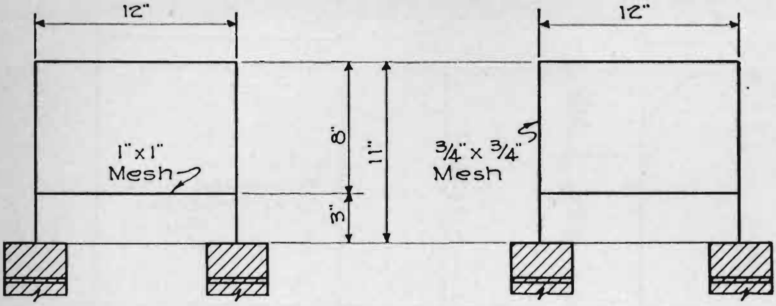






NO. 12

Fig. 24 continued



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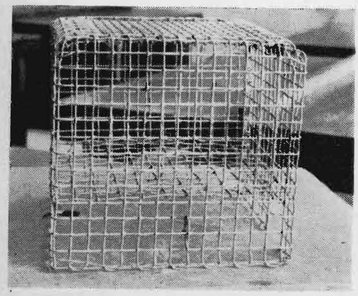

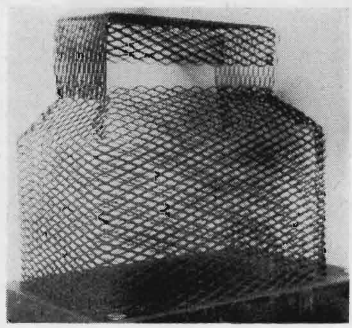

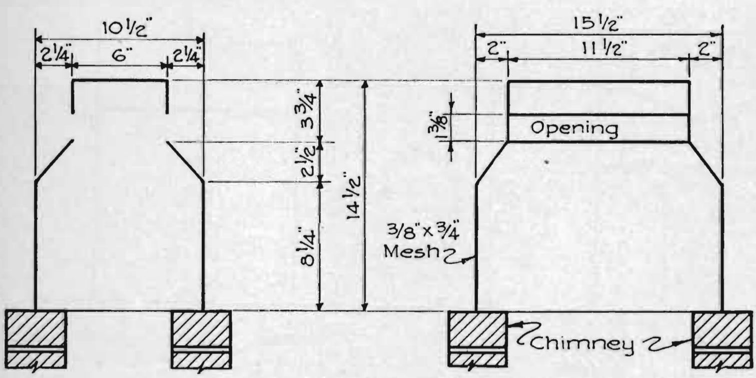

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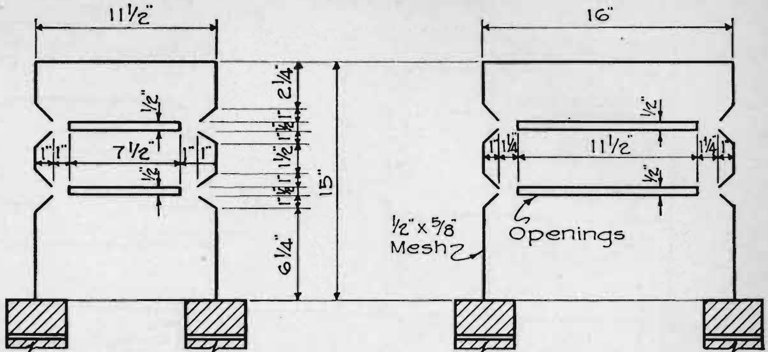
Fig. 24 continued



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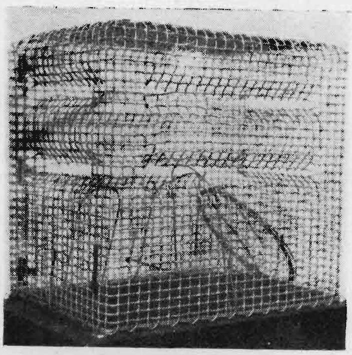

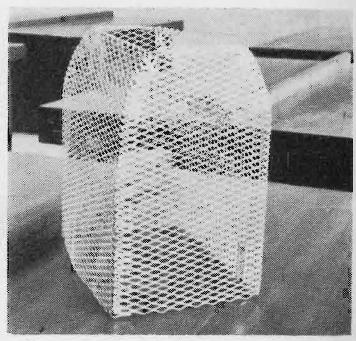

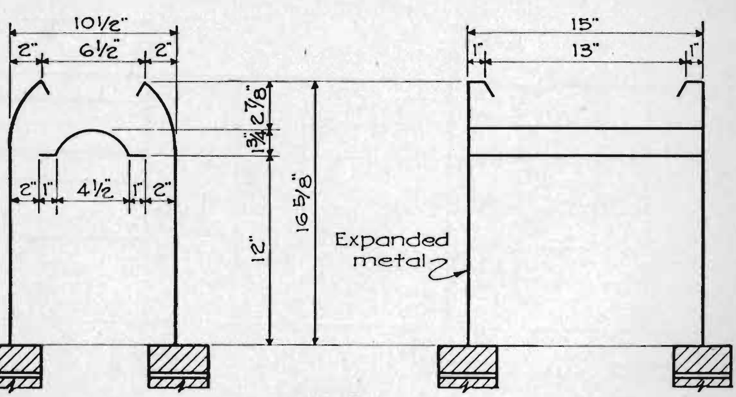

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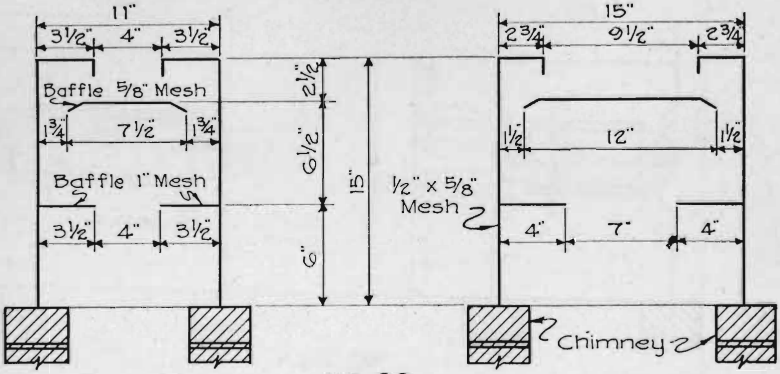
Fig. 24 continued



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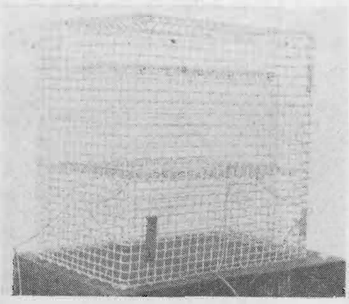

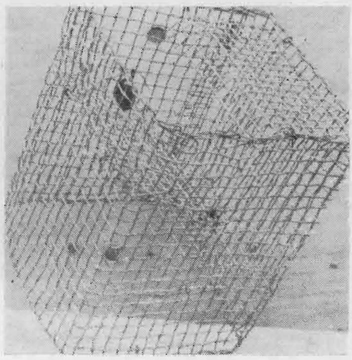

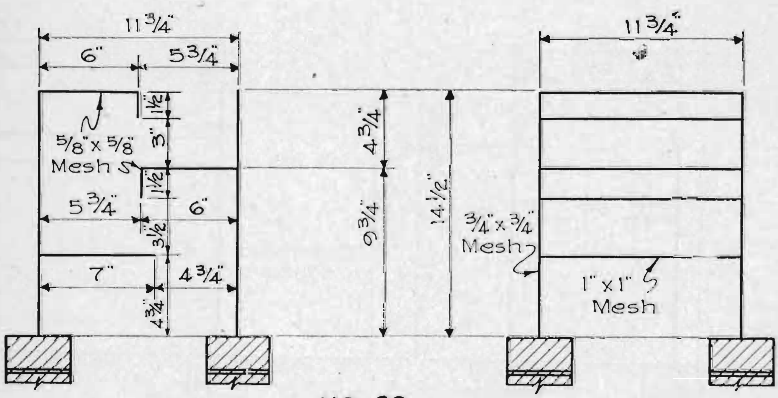

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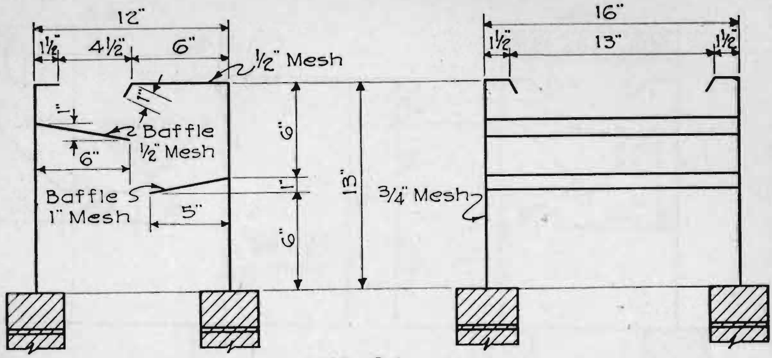
Fig. 24 continued



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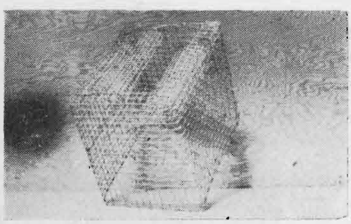

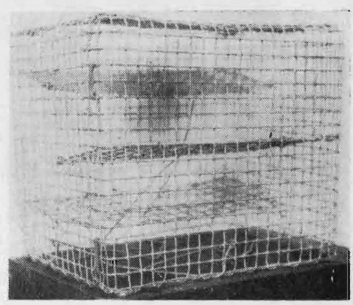

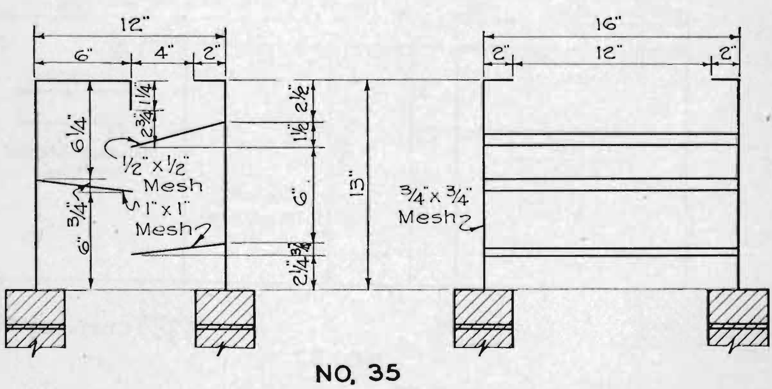

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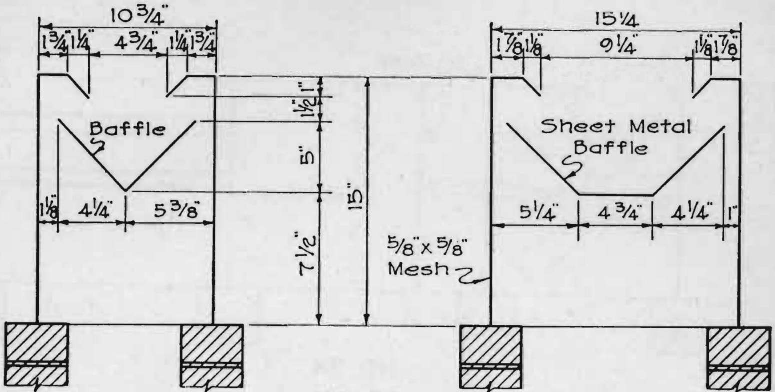
Fig. 24 continued



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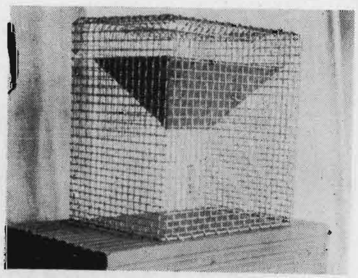

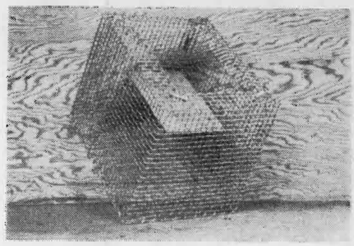

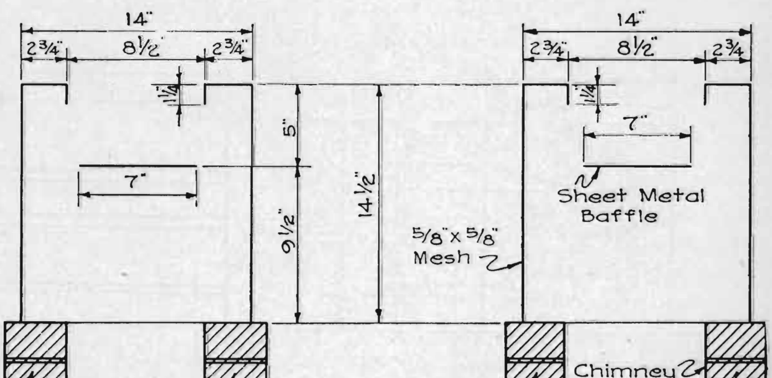

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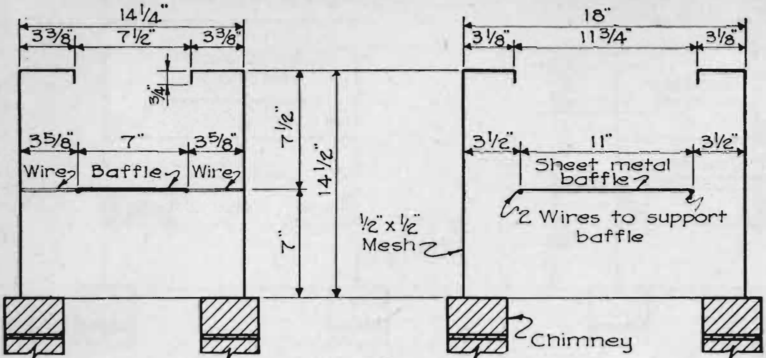
Fig. 24 continued



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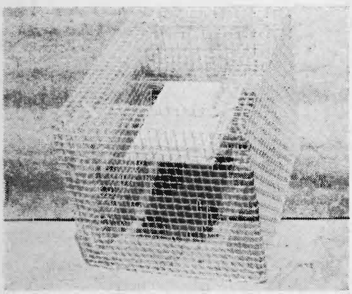

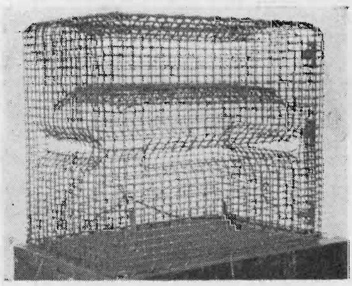

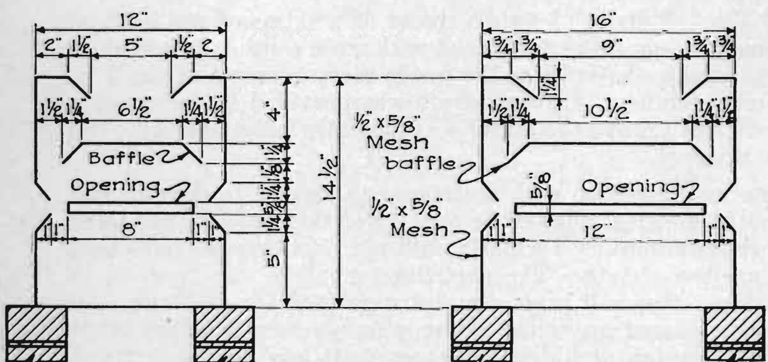

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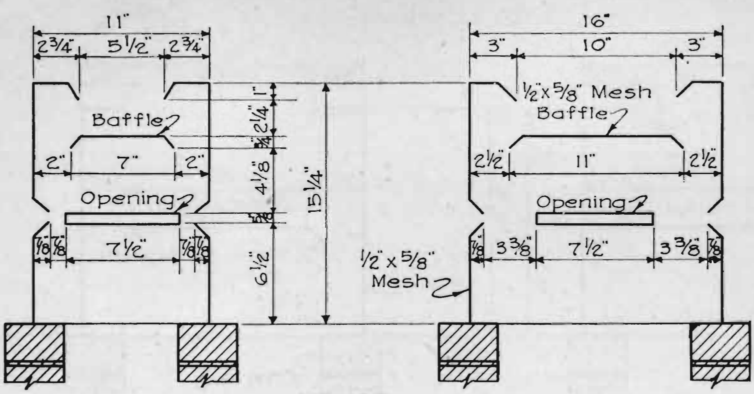

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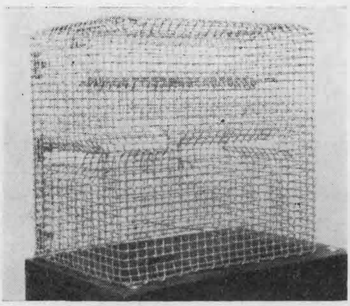

Fig. 24 continued

EFFECTIVENESS OF SPARK ARRESTERS

Extensive tests were carried out to determine the efficiency of the various available types of spark arresters in breaking up or retaining the soot particles.

For the first series of tests a model of a chimney was built of sheet metal as shown in fig. 25 and with cross sectional dimensions 9 by 13 inches, the same as the inside measurements of the 2 $\times$ 2½ brick chimney. Upward draft was provided by means of a fan sufficient to raise the larger soot particles 3 feet above the top of the chimney.

Tests were made on each arrester with respect to the size and amount of material allowed to pass. For this purpose unheated soot particles were used which would not pass through half-inch-mesh hardware cloth. The particles ranged in size from ½ to 1¼ inches. One-half gram samples were used for each run, and these were placed inside the chimney on a screen 9 inches below the top. The fan providing the cross draft was started first and then the one beneath the chimney, blowing the soot particles against the arrester. Each run lasted 60 seconds. Much of the soot was broken into fine particles by this operation. The material passing through the arrester was screened the second time and the weight of that which would not pass the half-inch mesh determined. The results are shown in table 7.

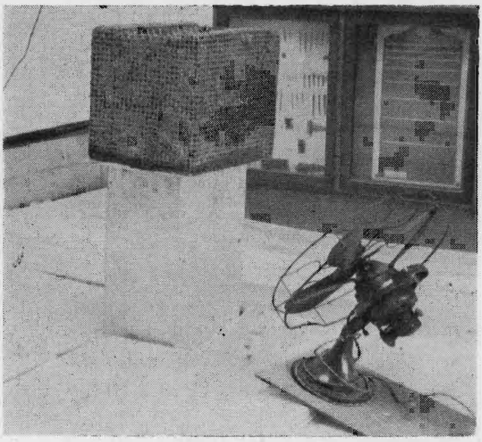

Fig. 25. Fan for producing side wind and sheets for collection of particles.

Further tests were made to determine the nature of heated soot particles after passing through the arresters. The procedure was the same as that above except that each half-gram sample was heated by the gasoline burner in the manner previously described. The particles remained approximately the same size after heating despite the loss in weight. They were easily broken when striking any part of the arrester, but some large fragments passed through the free openings of No. 21 and No. 22. In the former, 10.7 percent of the material passing through was over a half inch. No. 22 and No. 13 arresters showed up about equally in this respect with 5.8 and 5.2 percent, respectively. The primary difference was, however, that none of the fragments passing through No. 13 arrester was over ⅝ inch, the maximum that can get through the mesh, whereas with the other, some particles measured over an inch.

TABLE 7. SOOT PARTICLES ESCAPING FROM UNCLOGGED ARRESTERS.

Arrester No.	Weight in grams			
	Charge used		Escaping	
	Ea. sample	Total	Over ½″ (gms.)	Over ½″ %
		Cold		
13	0.5	10	0.42	4.2
21	0.5	10	1.20	12.0
22	0.5	10	0.91	9.1
		Heated		
13	0.5	4.96	0.26	5.2
21	0.5	4.96	0.53	10.7
22	0.5	4.96	0.29	5.8

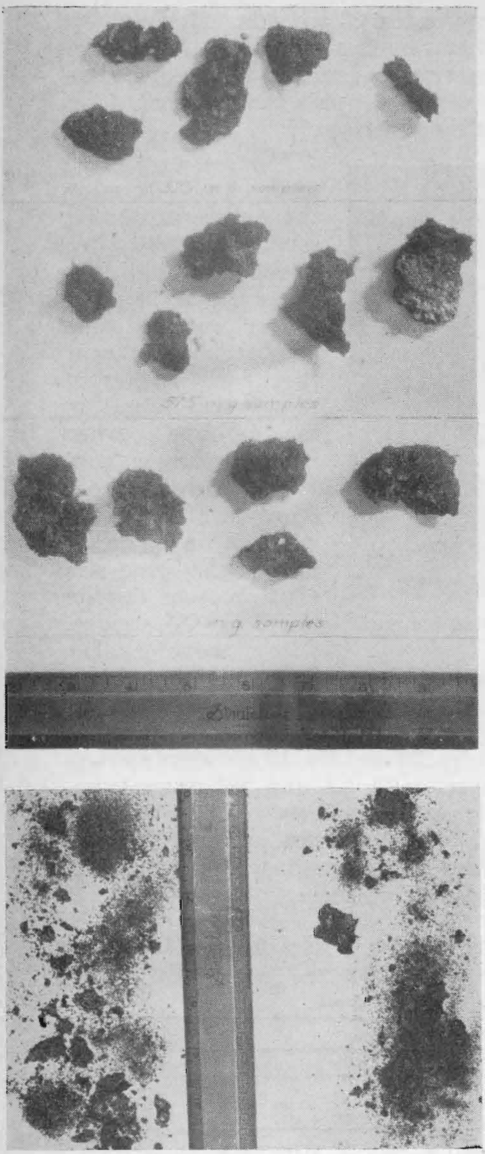

Fig. 26. Soot particles before and after going through arresters.

1. No. 13 Spark Arrester. In general this arrester did not break the particles up as fine as the other two. A large number were from $\frac{1}{4}$ to nearly $\frac{1}{2}$ inch, but only 4.2 percent by weight of the material was over $\frac{1}{2}$ inch and not larger than $\frac{5}{8}$. Anything of this size would be too small to start a fire.

2. No. 21 Spark Arrester. Conditions here were similar to those in the previous test except that a somewhat greater amount of the larger material passed through the free openings. The sloping sides below the openings did tend to keep a large amount of the material from getting out until broken up, but 12 percent of the material passing through was over $\frac{1}{2}$ inch and a considerable amount of this was over 1 inch and therefore not broken up at all.

It might be noted that this setup, having the wind at right angles to the openings, gave the greatest opportunity for large material to escape in both this and the preceding tests. Nevertheless, such condition would probably occur quite frequently in practice, and therefore this test is not considered unfair. There is reason to believe that even larger particles than those used could pass through the free openings.

3. No. 22 Spark Arrester. A sample of the material that passed through is shown in fig. 26. This shows that most of it was broken up quite fine, but 9.1 percent was over a half inch with a few pieces over an inch. All the larger material passed through the free openings on the side opposite the direction of the wind. The air stream caught these particles and in most instances carried them nearly horizontally through the openings.

These tests were followed by another series of tests which undertook to determine the efficiency of eight of the spark arresters on the market at the present time, as well as a special arrester (No. 36) which had been developed as a result of the earlier tests. The nine spark arresters of which specifications have been given previously were tested. All the arresters were artificially clogged by using glue mixed with sawdust.

A 16-inch fan (fig. 25) furnished the side draft. The center of the fan was located 9 inches below the top of the chimney and inclined at an angle of 30 degrees with the horizontal. The distance from the fan face to the nearest side of the arrester was maintained at 30 inches.

The grain blower used previously furnished the movement of the air currents within the chimney.

A model chimney was constructed of 24-gauge galvanized sheet metal. The over-all height was 49 inches with the inside dimensions increasing uniformly for a distance of 19 inches, the measurements of the base being 27″ × 27″. Beginning also at a point 30 inches from the top, the 9″ × 13″ rectangular cross section was gradually transformed into a circular cross section 14 inches in diameter. The circular section was developed through a distance of 10 inches. Located 9 inches from the chimney top was a metal tray made with a framework of ⅛-inch rod and covered with No. 3 wire mesh. The base of the chimney was placed 18 inches from the floor so as to accommodate the grain blower.

A framework of cheesecloth surrounded the model chimney, being placed 20 inches from the chimney top. The receiving table, as shown in fig. 25, was 7′ × 7′.

The 15 particles composing the typical charge placed in the chimney consisted of five soot samples each weighing 375, 575 and 775 milligrams respectively. Figure 26 shows the typical charge. The specimens were carefully placed on the metal tray within the chimney.

The fan furnishing the side draft was started, time being allowed for the gaining of full speed. The motor driving the blower was then started. At the expiration of 1 minute the blower and fan were stopped, the soot particles which had not passed through the arrester were rearranged on the tray and the

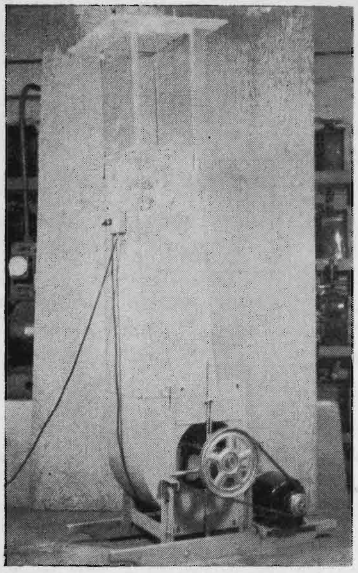

Fig. 27. Blower assembly.

process repeated. Five 1-minute runs were carried out for each arrester tested.

When the final run had been completed, the soot particles which had passed the arrester were taken from the cheesecloth. The larger specimens (weighing over 50 milligrams) were weighed individually. In addition, the total weight of the portion of the charge escaping the arrester was determined.

The base of the anemometer was held at the center of the side of the arrester and the body inclined so that the anemometer was in a plane parallel to that of the fan face. An average of 10 readings taken with the anemometer indicated a wind velocity of 710 feet per minute or 8 miles per hour on the near side of the arrester.

Ten readings were taken within the model chimney on the metal tray upon which the soot particles rested. An average was 1,772 feet per minute or 20 miles per hour.

Using previous standards a particle weighing over 375 milligrams will be termed "dangerous" and those between 150 and 375 milligrams will be called questionable.

Table 8 shows the number of larger size particles escaping the arresters tested.

Total original charge $(5 \times 375) + (5 \times 575) + (5 \times 775) = 7825$ milligrams.

All particles over 150 milligrams termed questionable.

All particles over 375 milligrams termed dangerous.

Figures at heads of columns indicate identification number of arrester used.

Throughout the test several observations were made with reference to the behavior of the soot particles within the several arresters under the action of the air flow. A few brief comments concerning each arrester follow.

No. 12. The body of the arrester contained no free openings. The larger sized particles escaped through the No. 2 chicken wire mesh of which the top is constructed. No dangerous sized particles escaped the arrester. A considerable number of ques-

TABLE 8. NUMBER OF SOOT PARTICLES ESCAPING SPARK ARRESTERS.

Wt. of particles mg.	Side wind at 30°									Side wind at 90°						
	Arrester No.															
	12	13	21	22	32	35	36	41	42	12	13	31	32	35	36	36*
50- 75	2	12	2	4	2	2	3	4	0	6	23	4	3	3	6	7
76-100	1	6	0	1	2	1	0	3	0	1	9	0	2	0	1	3
101-125	4	1	0	0	0	0	2	1	0	0	0	0	0	0	2	0
126-150	1	0	0	0	1	1	2	0	0	0	0	0	0	1	1	0
151-175	2	0	0	1	0	0	0	0	0	0	0	0	4	0	0	2
176-200	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
201-225	1	0	0	1	1	0	0	0	1	2	0	0	0	0	0	0
226-250	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
251-275	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
276-300	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
301-325	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0
326-350	0	0	3	1	0	1	0	4	1	0	0	2	0	0	0	0
351-375	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0
Over 375	0	0	4	4	0	1	0	4	2	0	0	5	0	2	0	0

*Baffle filled.

tionable sized particles did escape. The arrester showed good performance under test.

No. 13. This arrester had no free body openings. The percent of the total charge escaping was small. The arrester being completely enclosed prevented the passage of any particles of the dangerous or questionable sizes. As the result of this performance under test, this arrester would seemingly deserve an excellent rating.

No. 21. The arrester offered but little resistance to the escape of the soot particles from the openings near the top. No swirling motion of the particles was in evidence, but the air currents readily carried the particles from the arrester without serious breakage. Of the total charge escaping the arrester 65 percent of the escaped portion consisted of particles which have been termed dangerous. As a result of the test, the arrester in question should be classed as unsatisfactory.

No. 22. This arrester also allowed particles of dangerous size to escape.

No. 32. This arrester had no free openings except the one located in the top. Overhanging the top opening was a lip which, as previously stated, was effective in retarding the particles. Furthermore, the opening was guarded by a baffle. As shown in table 8, no specimens of a dangerous size and only a small percentage of questionable sized particles escaped the arrester. The material escaping was broken into fine particles.

No. 35. The particles would find their way between the baffle spaces and usually would be broken fine before they would escape the arrester chiefly through the top opening. However, several particles, including one large dangerous sized specimen, followed the path of the air currents directly and escaped the arrester without serious breakage. The total charge escaping was held within a reasonable figure. The results of this test would seemingly give the arrester a rating of fair.

No. 36. As previously described, the arrester had no free body openings except the one located in the top. Protecting this opening was a sheet-iron baffle in the form of an inverted pyramid placed 3 inches from the top of the arrester. Under the action of the air currents within the chimney the soot particles ascended into the arrester. Following the air currents, the particles traveled between the baffle and the arrester. Air velocity above the baffle being greatly reduced, the specimens fell into the basket-like baffle. Nine of the 15 particles composing the original charge entered the baffle on the first 1-minute run. No particles of the dangerous or questionable sizes escaped the arrester. This arrester allowed the smallest percentage of the original charge to escape.

No. 41. In this arrester the particles gained a rotary motion causing them to float from the openings in the side of the arrester. The top opening failed to offer passage to any of the particles except those that had been broken very fine. The lip protecting the top opening proved effective in preventing the escape of the particles. Because of the passage of the particles through the side openings the arrester gave unsatisfactory test results.

No. 42. This arrester was very similar to No. 41, except that the area of the side openings was smaller. As a result the arrester gave a corresponding better test. The top opening was not an offender in the passage of particles, the lip overhanging the opening being very effective in retarding the specimens. The results for the arrester were fair.

The test was continued under identical conditions except that the location of the fan furnishing the side draft was changed to 90° with the side of the arrester. The velocity of air currents striking the arrester was maintained at 8 miles per hour as before.

The five arresters giving the most satisfactory results in the previous test were selected for the experiment. In addition No. 31 was tested. No. 36 was tested as before, but as an additional test the basket-like baffle was filled with soot particles as might be the case after extended use. The results are included in table 8.

Filling the baffle of No. 36 lessened its ability to retain the test specimens. Two particles weighing between 151-175 milligrams passed the arrester. However, these are not dangerous, and even with the baffle filled the arrester gave very satisfactory results.

No. 31 gave unsatisfactory results. The lips or webs surrounding the top opening, being only 1 inch in width, offered but little resistance to the passage of particles.

No. 35 did not perform as effectively as in the previous test. The soot particles seemingly found a way through the sloping baffles and escaped the arrester more readily with a direct side draft.

The remaining arresters gave very good results and performed in a manner comparable to the previous test.

DESIGN AND TESTING OF NEW TYPES OF SPARK ARRESTERS

Considerable work was carried out on the design and testing of new types and designs of arresters. The new arrester (No. 36) gave superior results over any of the commercial models tested. The possibilities of using a sheet metal arrester in conjunction with a baffle were also investigated and were reported with the results of the study of the characteristics of the rising gas columns in chimneys.

From the results of the foregoing tests, it appeared possible to design an arrester with a top opening equal to or greater than the area of a chimney, using a baffle plate below this opening to deflect the rising gases and the soot particles against the sides of the arrester thus preventing their escape.

Such an arrester would offer the advantage of little interference with chimney draft even in case of complete clogging of the wire mesh with soot.

The first arrester was made 20.5 × 16.5 × 16 inches high of ½-inch mesh hardware cloth, intended for a chimney with an 8½ × 12½ inch opening at the top. This size opening is most commonly found among existing chimneys. An extension 4 inches wide was made on the inside of the top of the arrester.

A 10-inch multiblade furnace blower was used to furnish an air blast for the tests. The fan was arranged to discharge vertically, with the opening brought to 8½ × 12½ inches at the top of a metal pipe. (Figure 28.) An adjustable door made it possible to regulate the intake of the blower and thereby change the velocity in the pipe.

Balsa wood cut into shapes resembling soot particles of weights as shown in table 9 were used.

Four types or shapes of baffles were tried with this first arrester. They were: (1) Inverted pyramid (2) Crossed metal sheets in x shape (3) Flat sheet metal (4) Flat sheet of ⅜-inch mesh hardware cloth.

TABLE 9. WEIGHTS OF INDIVIDUAL BALSA WOOD AND CORNSTALK PITH PARTICLES.

The following weights, in milligrams, comprised the 50 balsa wood specimens used in testing arrester No. 38.

200	230	250	300	350	400	430	480	525	600	675	710	
200	235	285	300	350	400	450	480	540	600	700	715	850
220	245	300	310	350	410	450	490	550	660	700	750	1290
220	245	300	320	350	425	470	510	590	660	710	750	

Weights of cornstalk pith particles used

45	75	105	115	125	145	175	190	230	270	375	420	495
70	100	110	120	140	170	180	225	245	275	390	430	

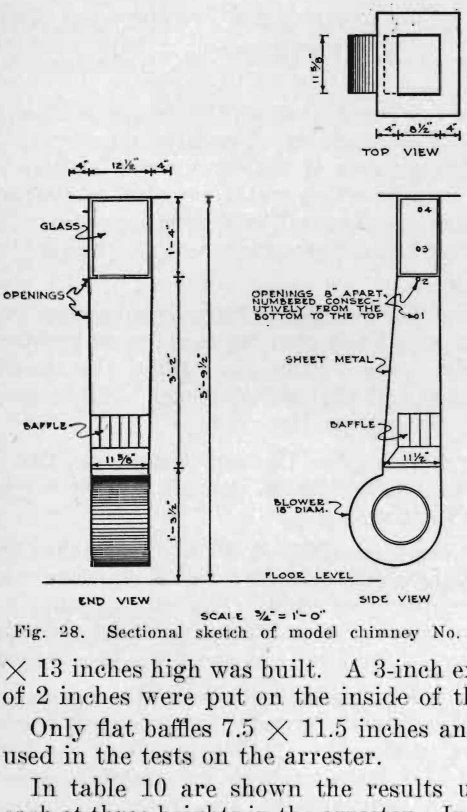

Fig. 28. Sectional sketch of model chimney No. 1.

With the exception of the screen baffle, all were effective in keeping the test particles of balsa wood from getting out of the arrester.

It appeared that smaller over-all dimensions might be used effectively and that the flat metal baffle was apparently as efficient as the others. The flat baffle also offered the advantages of simplicity and not deflecting a cross wind down the chimney.

After the preliminary tests, an arrester 14.5 $\times$ 18.5 $\times$ 13 inches high was built. A 3-inch extension and an overhang of 2 inches were put on the inside of the top of the arrester.

Only flat baffles 7.5 $\times$ 11.5 inches and 8.5 $\times$ 12.5 inches were used in the tests on the arrester.

In table 10 are shown the results using the two baffle sizes each at three heights in the arrester. In one series, arresters were partially clogged with glue and sawdust to simulate actual conditions.

No dangerous particles escaped the arrester with either baffle at any height if the overhanging edge was provided at the top. None escaped the clean arrester without the edge. Particles escaped the clogged arrester without the overhanging edge only at the excessive flue velocity of 2,000 ft./min., which appears to

TABLE 10. PARTICLES ESCAPING FROM ARRESTER NO. 38.

Size of baffle	Ht. of baffle above chimmey	Overhanging edge at top					
		Flue vel. ft./min.	With		Flue vel. ft./min.	Without	
			clean	clogged		clean	clogged
7.5 x 11.5	5″	700*	0	0	736*	0	0
		900	0	0	1200	0	0
		2000	0	0	2000	0	20
	6½″	900	0	0	1200	0	0
		2000	0	0	2000	0	16
	8″	900	0	0	1200	0	0
		2000	0	0	2000	0	1
8.5 x 12.5	5″	900	0	0	1200	0	0
		2000	0	0	2000	0	19
	6½″	900	0	0	1200	0	0
		2000	0	0	2000	0	10
	8″	900	0	0	1200	0	0
		2000	0	0	2000	0	1

*Note: So few particles reached even the baffle that further tests at this velocity were considered unnecessary. Each figure represents 5 charges of 50 particles each as indicated in table 9.

be much in excess of that to be expected in a house chimney. Cross winds had no appreciable effect.

A screen baffle is not effective, as shown in table 11. Each observation shows the number escaping from 100 particles used. Out of 2,100 particles used for each type of baffle 115 escaped when the screen was used and only two when the solid sheet was used. The latter escaped only at the highest velocity.

Tests of the solid baffle showed equally satisfactory results at heights of 5 inches, 6½ inches and 8 inches for the lower velocities, and best results at 8 inches for the highest velocity. To avoid affecting the chimney draft it seems necessary to maintain a free cross section equal to or greater than that in the

TABLE 11. PARTICLES ESCAPING BETWEEN SOLID AND SCREEN BAFFLES IN ARRESTER NO. 38 PARTIALLY CLOGGED AND PROVIDED WITH (A) SOLID SHEET BAFFLE AND (B) SCREEN BAFFLE.

Ht. of baffle	Flue velocity ft./min.						Total	
	1000		1250		1460			
	a	b	a	b	a	b	a	b
4	0	1	0	3	0	11	0	15
5	0	0	0	5	1	12	1	17
6	0	1	0	6	0	12	0	19
7	0	2	0	6	0	20	0	28
8	0	1	0	2	1	9	1	12
9	0	0	0	6	0	9	0	15
10	0	0	0	3	0	6	0	9
Total	0	5	0	31	2	79	2	115

Note: Each figure represents particles escaping from 100 used.

TABLE 12. EFFECT OF VARYING HEIGHT AND SIZE OF BAFFLE WITH SIDE, END AND CROSS WINDS UPON THE NUMBER OF PARTICLES ESCAPING CLEAN AND PARTIALLY CLOGGED ARRESTER NO. 38.

Flue velocity ft./min.	Size of baffle	4″ Ht.				5″ Ht.				6″ Ht.				7″ Ht.				8″ Ht.				9″ Ht.				10″ Ht.			
		N	S	E	D	N	S	E	D	N	S	E	D	N	S	E	D	N	S	E	D	N	S	E	D	N	S	E	D
1000	4.5″ x 8.5″		5	5	2		4	2	5		3	5	4		4		3		1	2			1		2		2		3
	5.5″ x 9.5″		2	6	2			3			1	1	2		1		1		1	4	1	1			1				
	6.5″ x 10.5″		5	3			2				1	1	1		1	1													
	7″ x 11″		1	1	1		2				2		1																
1250	4.5″ x 8.5″	1	26	15	9		20	10	8	1	9	8	1		9	7	1	1	8	2	4		6	4	4	3	3	3	4
	5.5″ x 9.5″		9	8	6		4	5	6		4	2	3		1	5	1			1	1	1		1	1		1		1
	6.5″ x 10.5″		6	3	2		5	2	2		3	3			2	2				1	2								
	7″ x 11″		4	4			4	1			4	3	1		2		1												
1460	4.5″ x 8.5″	11	25	14	19	6	21	12	17	2	19	10	14	10	12	5	13	5	6	6	3	9	7	5	5	2	11	5	9
	5.5″ x 9.5″	2	15	6	4		8	8	8	1	9	4	7	2	2	7	9	1	1	4		1	1		2	1			
	6.5″ x 10.5″	1	8	4		2	5	4	1		4	2		3			1			1	1					1			
	7″ x 11″		10	4	1	2	6	1			5	1			2			1			1		1	2					

Figures show number of particles escaping arrester out of a possible 200.
Four charges of 25 each in clean arrester and 4 charges of 25 each in a partially clogged arrester.
Column headings show direction of cross wind. N=None; S=Side; E=End; D=Diagonal.

chimney itself. To attain this, the baffle should not be placed closer than perhaps 3 inches from the top or bottom of the arrester.

Another series of tests was undertaken in order to determine the best size of baffle, the proper position of the baffle above the chimney opening, and the effect of environmental conditions such as side wind, velocity of air stream, size of sparks and the condition of the screen. The model chimney as previously described was used in these tests also.

Twenty-five balsa wood particles were used with weights in milligrams as given below:

40	285	350	500	700
230	300	380	520	710
235	310	390	540	715
250	320	430	550	750
260	330	475	660	850

All except one may be classed as at least questionable and 14 as definitely dangerous in size. These particles were fed into the air stream through a small aperture in the chimney wall. The number and sizes of the particles that escaped through the opening in the top of the arrester were recorded.

Each test represented in table 12 comprised 4 charges of 25 particles with a clean arrester and 4 similar charges with one partially clogged. Figures in the body of the table show the number escaping out of a possible 200. The entire series represents 67,200 particles placed in the flue.

The effect of four variables upon the behavior of the arrester was investigated; they were:

1. Size of baffle plate—4.5″ × 8.5″, 5.5″ × 9.5″, 6.5″ × 10.5″, 7″ × 11″. The baffle was in all cases smaller than the chimney opening (9″ × 13″).
2. Height of baffle plate (4″, 5″, 6″, 7″, 8″, 9″, 10″).
3. Air velocity in flue (1000, 1250 and 1460 ft./min.).
4. No cross wind, cross wind from side, end and at 45°. (All cross wind velocities 10 mi. per hr. (880 ft./min.).)

Similar tests made without a baffle plate are reported in table 13. Each figure represents the number escaping out of a possible 200.

TABLE 13. PARTICLES ESCAPING ARRESTER NO. 38 WITH BAFFLE PLATE REMOVED.

Flue vel. ft./min.	Cross wind			
	None	Side	End	Diag.
1000	66	42	49	62
1250	79	80	88	98
1460	98	126	99	118

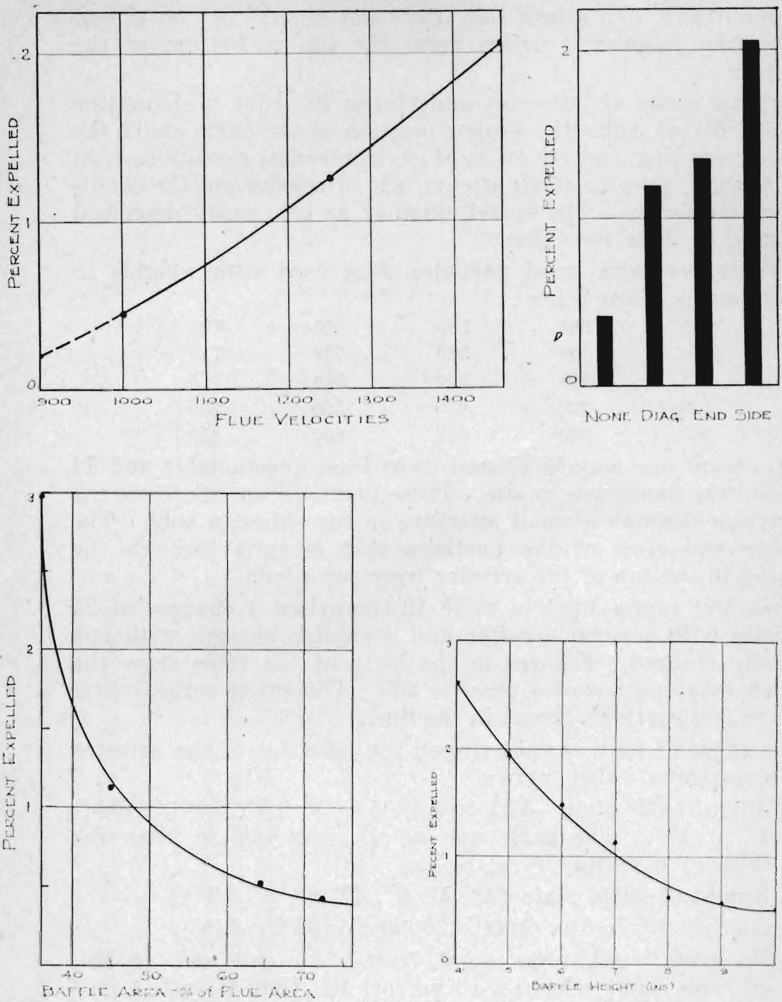

Fig. 29. Effect of variables on performance of arrester.

Conditions in this test were doubtless on the severe side. Velocities in the flue were probably greater than those existing in a dwelling chimney even in case of a "burnout." Soot particles striking the screen on baffle plate would usually be broken into finer particles whereas the pieces of balsa wood would be thrown from one part of the arrester to another and sometimes eventually escape.

The principal object, however, was to determine the effect of the various factors on performance.

Table 12 shows that at a velocity of 1000 ft./min., some particles escaped past the smallest baffle plate even at the 10-inch height although the number decreased appreciably at a height of 7 inches or higher. The second size passed no particles at the 10-inch height. The effectiveness increased generally as the size of the baffle plate was increased.

The effects of the various variables on performance are shown graphically in fig. 29. It should be pointed out at the outset however that in all cases the baffle was quite effective in preventing the escape of the balsa wood particles. Of the 67,200 particles charged into the chimney covered by any one of the arresters provided with a baffle plate, only 849 or 1.26 percent escaped. When the baffle plate was removed, 1005 out of 2400 or 41.9 percent escaped.

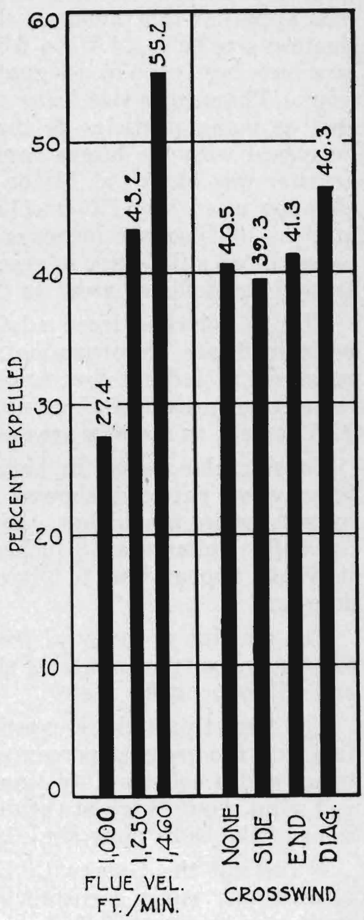

Fig. 30. Performance of No. 38 arrester without baffle plate.

A discussion of the principle of operation may explain the arrester's relative effectiveness and also help in the determination of dimensions which will produce the desired results. Soot sparks emitting from the chimney at a high velocity are likely to strike the baffle plate, with the probability that they will be fractured into particles harmless in size. Those which are deflected by a cross wind will strike the screen at the side or top between the overhanging edge and the side. Unless these are likewise broken into harmless sizes, they cannot escape. If the arrester should become partially or completely clogged, the air currents passing the baffle may tend to direct the soot particles toward the free opening in the top. In such a case, however, the deflection of gas currents by the baffle tends to increase the cross section of the gas stream thus decreasing its velocity of flow. This decrease in velocity greatly reduces the transporting power with the result that the few particles of dangerous size are not carried out. Balsa wood particles frequently were thrown about the top of the arrester from one side to another but failed to go out the free opening.

A screen baffle plate cannot give the same satisfactory results. This failure is not the result of inability to obstruct particles of dangerous size, because this can be controlled by the size of the mesh in the screen. It fails instead because the gas currents are not deflected by the screen but pass directly through it. These gas currents, passing through the screen, then carry any soot particles out the free openings. Many chimneys are poorly constructed and do not provide the draft necessary for satisfactory operation. A spark arrester should cause as little disturbance as possible to the flow of gases. From fig. 29 (bottom, left) it is apparent that much of the effectiveness was lost when the smallest size baffle (4.5″ × 8.5″) was used. Percentages of flue area have been used to designate the baffle size rather than dimensions. The second size baffle (5.5″ × 9.5″) passed only 38 percent as many particles as the smaller one. Benefits, however, decreased with the larger sizes. The cross section of the spark arrester was 14.25″ × 18″ or 256.5 square inches. That of the chimney was 9″ × 13″ or 117 square inches. A baffle plate as large as 139.5 square inches or 112 percent of the flue area could be used and still leave, in case of complete clogging, a free area around the baffle as great as that in the chimney itself.

This is not considered advisable, however, as the benefits to be gained are problematical. It would appear desirable to maintain as large a free area as possible to cause a minimum restriction in case of clogging. The largest size baffle used was 72.5 percent as large in area as the cross section of the flue.

Considerable range in baffle height is possible. Tests with balsa wood particles showed considerably greater tendency to by-pass baffles placed low. Little benefit was gained by placing the baffle higher than 8 inches. From the practical standpoint it would appear best to place it at one-half the height of the arrester.

The amount of material escaping the arrester increased with the flue velocity in almost a straight line relationship both with and without a baffle plate.

The fewest particles escaped when no cross wind existed. The fact that the greatest percentage escaped when exposed to a side wind, and a considerably lesser percentage when exposed to an end wind, would suggest the desirability of modifying the dimensions of the baffle plate slightly, making it wider and shorter.

Following the tests with balsa wood particles, similar ones were made using cornstalk pith. The general results were similar to those using balsa wood. The practical results, however, make the test even more conservative. The specific heat of soot as light as cornstalk pith would be so low that a very large piece would be necessary to cause ignition. On the other hand, particles of this size would be so fragile as to be broken upon contact with either the baffle plate or screen.

THE EFFECT OF SPARK ARRESTERS UPON THE FLOW OF AIR THROUGH MODEL CHIMNEYS

The lack of available information on the effect of clogged spark arresters upon the flow of gases in a chimney prompted this investigation. Much is known of chimney construction, chimney characteristics and of some of the factors which influence the performance of a chimney.

The following statements are taken from the Heating and Ventilating Guide of the A.S.H.V.E. (1):

"Draft, in general, may be defined as the pressure difference between the atmospheric pressure and that at any part of an installation through which the gases flow. Since a pressure difference implies a head, draft is a static force. While no element of motion is inferred, yet motion in the form of circulation of gases through an entire boiler plant installation is the direct result of draft. This motion is due to the pressure difference, or unbalanced pressure, which compels the gases to flow. Draft is often classified into two kinds according to whether it is created thermally or artificially, (1) natural draft or thermal draft, and (2) artificial or mechanical draft.

"Natural draft is the difference in pressure produced by the difference in weight between the relatively hot gases inside a natural draft chimney and an equivalent column of the cooler outside air, or atmosphere. Natural draft in other words, is an unbalanced pressure produced thermally by a natural draft chimney as the pressure transformer and a temperature difference. The intensity of natural draft depends, for the most part, upon the height of the chimney above the grate bar level and also the temperature difference between the chimney gases and the atmosphere."

Natural draft as used in this manuscript is interpreted as the difference in pressure produced by a difference in weight between the relatively hot gases inside a natural draft chimney and an equivalent column of the cooler outside air, or atmosphere.

Kratz (3) has the following to say in discussing the "Use of the Draft Gauge for Testing Chimneys in Warm Air Heating Plants":

"It is probable that no one factor governing the installation of warm air furnaces gives the installer more concern than the question of whether or not an adequate chimney has been provided."

He lists the common causes of poor draft as: (1) Cooling of the chimney gases, (2) excessive friction, (3) wind effects, (4) insufficient height.

"If the top of the chimney is not carried well above the ridge of the roof, the wind may be directed over the top in such a manner that a back draft is produced, thus destroying the draft. Trees or other objects located near the chimney may also produce this effect.

"Any one of the defects enumerated may be insufficient to interfere very seriously with the action of the chimney, and where trouble is encountered it is usually caused by a combination of factors. In any case, the proper method of procedure is first to measure the draft by means of a draft gauge. This gives very definite proof that the chimney either is or is not defective. When such proof is obtained, the remedy may then be found by a thorough examination and by the process of elimination, taking account of various possible defects which have been enumerated and listed."

A discussion of the characteristics of chimneys is given by the A.S.H.V.E. Guide (1) (p. 465). The general operating characteristics of the chimney are compared with those of a centrifugal pump and also of a centrifugally-induced draft fan. A statement is made that the draft-capacity curve of the chimney corresponds to the head-capacity curve of the pump and also to the dynamic-head capacity curve of the fan.

The draft required to effect a given rate of burning the fuel as measured at the smokehood is dependent on the following factors:

1. "Kind and size of fuel.
2. Combustion rate per square foot of grate area per hour.
3. Thickness of fuel bed.
4. Type and amount of ash and clinker accumulation.
5. Amount of excess air present in the gases.
6. Resistance offered by the boiler passes to the flow of gases.
7. Accumulation of soot in the passes.

"Insufficient draft will necessitate additional manipulation of the fuel bed and more frequent cleanings to keep its resistance down. Insufficient draft also restricts the control by adjustment of the dampers.

"The quantity of excess air present has a marked effect on the draft required to produce a given rate of burning, and it is often possible to produce a higher rate by increasing the thickness of the fuel bed." (p. 487.)

Senner and Miller (10) list the following common faults in chimney construction:

"Lack of a tight flue. A flue free from leakage is unusual. Every flue should be tight enough to prevent the escape of smoke. A leaky flue is the most frequent cause of heating troubles, high fuel bills, and destructive fires.

"The top of the chimney should extend at least 3 feet above flat roofs and 2 feet above the ridge of peak roofs, and it should not be on the side of the house adjacent to a large tree or a structure higher than itself for these may cause eddies and force air down the chimney."

Stanworth (11) in discussing the flow of gases in a chimney states:

"When a fluid issues from any opening it is found that due to eddy currents and friction, the stream has a sectional area less than that of the opening. The relative size varies with the velocity of the fluid, but for air it is found by experiment that the stream has .65 of the sectional area of the opening. In order to produce smooth flow, it is advisable to use a chimney-pot, tapered to a sectional area of about .65 of the narrowest portion of the flue. In most modern fires this is least at the throat just above the fire, and varies from about 80 to 100 square inches. Such a chimney pot will produce smooth flow with the greatest velocity. The chimney is most efficient, however, when the gases enter the air with the least velocity, because then the pressure is greatest. The effect may be produced by making the pot diverging in the upper portion." (p. 7).

In discussing the factors which may interfere with the performance of a chimney Stanworth states that in one way or other, winds are the cause of at least 90 percent of smoky chimneys. (p. 13).

Tests in this investigation indicated that a maximum temperature of 1,500 degrees could be expected in the chimney for the average dwelling and this only under burnout conditions. Calculations were made for the theoretical maximum velocity attained by the rising flue gases in a chimney whose diameter is 0.8 foot. The maximum velocity will occur when there is a maximum temperature in the chimney. The maximum velocity, in round figures, was found to be 740 feet per minute.

Considerable complaint has been made against spark arresters as a result of smoke damage caused when the arrester becomes clogged. There has been some feeling that even when clean, they interfere with normal chimney draft. Very little is known as to how much resistance the various types of spark arresters offer to the flow of air, and no information is available as to how much they will interfere with the performance of a natural draft chimney.

This part of the bulletin will discuss:

1. The effect of partially clogged and completely clogged spark arresters upon the flow of air in model chimneys.

2. The effect of partially clogged and completely clogged spark arresters upon the flow of gases in a natural draft chimney.

3. The effect of baffle size and location in arrester No. 38 upon the flow of air through a model chimney.

By the use of forced draft a large number of variables would be eliminated; however, the conditions which exist in a chimney would not be exactly duplicated. In a model chimney equipped with a blower the difference in pressure produced is above atmospheric pressure, whereas in a natural draft chimney which is operating under normal conditions, the difference in pressure is produced by a difference in weight between the gases inside the chimney and an equal column of outside air, and the pressure inside the chimney is less than atmospheric pressure. A further comparison of the tests would be that a maximum positive pressure is produced at the bottom of the model chimney, and in the natural draft chimney there is a maximum negative draft produced at the bottom of the chimney. The two will approach atmospheric pressure near the top of the chimney, and the resistance offered by the arresters to the flow of air should be representative of the resistance offered to the flow of gases.

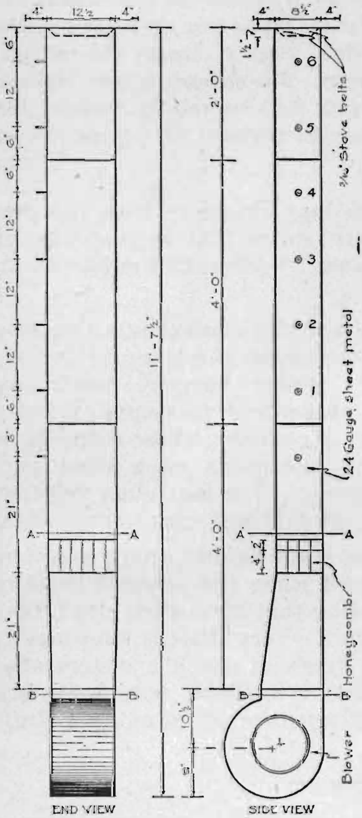

Fig. 31. Elevation of model chimney.

The blower used previously and illustrated in fig. 27 was used; however, a longer extension was provided as shown in fig. 31. The openings in the side were located as shown on the drawings, and the number on the openings corresponds to the pressure readings at these points recorded in fig. 34. By using different sections or by adding sections, the height of the chimney could be varied. Adjustable shutters made it possible to regulate the intake of the blower and thereby change the velocity of the air in the chimney.

Two draft gauges were used, a number 1-DL-1 draft gauge with a scale range of 0 to —.1 of an inch of water and a dry type B portable draft gauge with a scale range of 0 to 2 and 0 to —2.0 inches of water, depending upon the range of pressure encountered. Both gauges were manufactured by the Hays Corporation, Michigan City, Ind. The 1-DL-1 gauge could be adjusted to take positive readings up to .02 inch of water but performed much better if used only to detect negative differences in pressure.

Connection from the draft gauge to the chimney was made by means of ⅛-inch rubber tubes. A multiple draft gauge connection made it possible to take readings at any one of the different locations in the chimney by merely opening a stopcock.

An Alnor (Boyle System) velometer, manufactured by the Illinois Testing Laboratories, Inc., Chicago, was used to measure the velocity of the air flowing through the chimney. The instrument has two scale ranges: a low range of 0 to 250 and a high range of 0 to 2,500 feet per minute. All of the readings taken in this investigation were on the high range and with a jet type number 2425-18. The instrument was designed to take intermittent readings of very short duration in temperatures as high as 1,000° F. The accuracy of the readings was within 3 percent of full scale readings. The draft gauge, velometer and spark arrester in place ready for test are shown in fig. 32. A honeycomb baffle inserted in the model chimney tended to produce straight-line flow of the air.

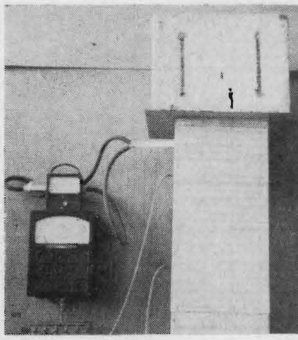
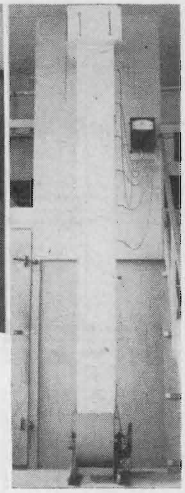

Fig. 32. Apparatus for observing pressures.

After observing actual clogging in the field, an effort was made to approach the nature of this clogging in the laboratory by artificial means. The meshes of each arrester were clogged approximately 40 percent with glue and sawdust (fig. 33, left).

Under the most extreme conditions the wire mesh in a spark arrester may become completely clogged. Arresters completely clogged by fibered plaster and shredded cornstalks are shown in fig. 33, right. The rough surface on the interior of the arrester represented, to a certain degree, actual clogging conditions.

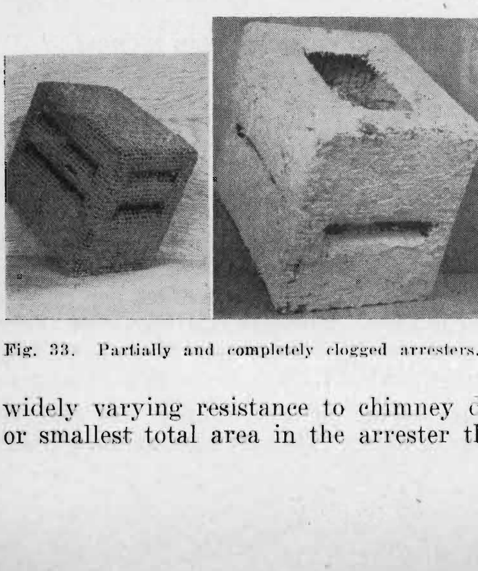

Fig. 33. Partially and completely clogged arresters.

In a clogged condition, the various arresters will present widely varying resistance to chimney draft due to the critical or smallest total area in the arrester through which all of the gases must pass. This total area is termed the "free" opening. A few of the arresters have no free area because no openings are provided other than those in the mesh. The amount of free area in any arrester refers to openings, in the top or sides of the arrester, which are larger than the size of mesh of which the arrester is constructed.

In the No. 38 arrester the size of the free area is determined by the area of the opening in the top of the arrester, whereas in the case of the No. 22 arrester the area of free opening is determined by rectangular openings cut in the sides of the arrester. The amount of free area in the No. 34 arrester is determined by the size of baffle and the height between the baffles.

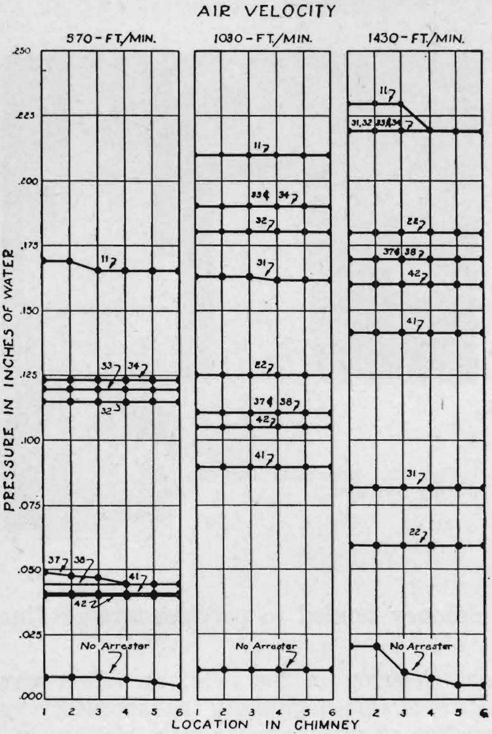

Fig. 34. The effect of completely clogged spark arrester upon the pressure of air flowing through a large model chimney.

The amount of free area in each arrester is as follows:

FREE OPENING IN SPARK ARRESTERS (SQUARE INCHES).

No. 11 = 0	No. 31 = 60	No. 36 = 44
No. 12 = 0	No. 32 = 28	No. 37 = 72
No. 13 = 0	No. 33 = 35	No. 38 = 88
No. 21 = 32	No. 34 = 44	No. 41 = 70
No. 22 = 38	No. 35 = 44	No. 42 = 74

The short model chimney was used in making this test. The blower was set in operation and the velocity of the air flowing through the chimney was regulated first at 945 feet per minute and later at 1,460 feet per minute. Pressure readings were taken at each of the openings, using each of the arresters, and the data for the tests are recorded in table 14.

The velocity of the air flowing in the chimney was checked first. Reductions were noted after. Then by placing an arrester

TABLE 14. THE EFFECT OF PARTIALLY CLOGGED SPARK ARRESTERS UPON THE FLOW OF AIR IN MODEL CHIMNEYS.

The Short Model Chimney

Arrester No.	Pressure (.001″ water) at specified locations, 945 ft./min.				Pressure (.001″ water) at specified locations, 1460 ft./min.				Velocity of air in chimney ft./min.			% of 660 fpm	% of 1015 fpm	% of 1470 fpm
	1	2	3	4	1	2	3	4						
11	5	0	0	0	0	0	0	0	665	1,005	1,440	99.3	99.0	98.0
22	1	0	0	0	0	0	8	1	660	995	1,470	100.0	98.0	100.0
31	0	0	0	0	1	0	0	0	..	.....	.....	.....	.....	.....
32	2	0	0	0	6	3	2	2	645	1,005	1,450	97.7	99.0	98.6
33	15	12	12	14	25	24	24	21	620	915	1,370	94.0	90.2	93.2
37	2	0	0	0	0	0	0	0	650	1,000	1,440	98.5	98.5	98.0
38	2	0	0	0	2	2	2	1	645	995	1,435	97.7	98.0	97.5
41	1	0	0	0	6	3	2	1	645	995	1,420	97.7	98.0	96.5
42	0	0	0	0	0	0	0	0	660	1,005	1,435	100.0	99.0	97.5
					open chimney				660	1,015	1,470	.....	.....	.....

The Long Model Chimney

Arrester No.	Velocity of air in open chimney 580 ft./min. — Pressure (.001″ water)* at specified locations						Velocity of air		Velocity of air in open chimney 1050 ft./min. — Pressure (.001″ water)* at specified locations						Velocity of air		Velocity of air in open chimney 1300 ft./min. — Pressure (.001″ water)* at specified locations						Velocity of air	
	1	2	3	4	5	6	With arrester	% of 580	1	2	3	4	5	6	With arrester	% of 1050	1	2	3	4	5	6	With arrester	% of 1300
11	1	1	0	0	0	0	560	96.5	12	10	6	4	5	4	1050	100.0	17	12	9	4	6	4	1300	100
22	1	0	0	0	0	0	560	96.5	14	10	8	4	5	3	1020	97.1	17	14	9	3	5	4	1300	100
31	1	0	0	0	0	0	570	98.3	11	10	6	4	5	4	1040	99.0	20	15	10	5	6	5	1300	100
32	1	1	0	0	0	0	570	98.3	13	10	6	4	5	3	1050	100.0	19	14	10	5	8	5	1300	100
33	6	5	5	4	4	3	530	91.4	21	21	20	17	19	16	1020	97.1	26	25	25	23	24	24	1200	92
34	3	2	2	1	2	1	540	93.1	21	19	16	13	14	12	1000	95.2	24	22	21	15	19	15	1210	93
37	1	0	0	0	0	0	550	94.8	16	13	10	5	6	4	1040	99.0	20	15	11	5	9	5	1300	100
38	1	1	0	0	0	0	540	93.1	13	10	8	5	6	4	1030	98.1	20	15	12	6	10	6	1300	100
41	1	1	0	0	0	0	560	96.5	13	10	8	5	5	4	1040	99.0	20	15	10	5	8	5	1300	100
42	1	0	0	0	0	0	560	96.5	13	10	8	5	6	4	1030	98.0	19	14	10	4	7	5	1300	100
None	0	0	0	0	0	0			12	9	7	4	4	1			16	14	10	3	6	3		

*Pressure above atmospheric.

on the chimney the velocity was observed in five places at the top of the chimney by means of the velometer. Readings were taken 2.5 inches from each corner and in the center of the chimney. Three open chimney velocities were used. Only the average velocity reading is shown in the table.

The partially clogged spark arresters did not affect the pressure in the chimney or the velocity of the air enough to make the results significant.

The pulsating flow of the air produced by the fan could not be corrected even though a honeycomb baffle was used to reduce eddy currents. A higher chimney was constructed and the tests continued.

The testing procedure was essentially the same as that previously described for the small model chimney except for the fact that in the case of the large model chimney there were six openings in the height of the chimney from which pressure readings could be taken. All of the arresters were checked in this manner using open chimney air velocities of 580, 1050 and 1300 ft. per minute. (Table 14.)

Velocity readings recorded in the tables were obtained by taking the average of three sets of full readings. All of the velocity readings were taken at the top of the chimney. The pressure readings recorded in the tables were obtained by taking the average of five sets of readings at each station. Only the averages are shown in the tables. From the bottom to top of chimney the openings are numbered from 1 to 6.

Only arresters 33 and 34 had much effect upon the pressure when the air velocity was 580 feet per minute. However, the velocity was reduced as much as 8.6 percent in the case of No. 33 and 6.9 percent with Nos. 34 and 38. As the velocity of the air increased, the pressure produced in the chimney increased. All of the arresters produced practically the same results for the velocities used except Nos. 33 and 34.

THE EFFECT OF CLOGGED ARRESTERS UPON THE FLOW OF AIR IN A LARGE MODEL CHIMNEY

The wire meshes of all of the arresters used in making this series of tests were completely clogged.

Procedures similar to those used in connection with the short chimney were followed, except that in this case open chimney velocities of 425, 570, 805, 1030 and 1430 feet per minute were used. The data for each velocity are shown in table 15 and fig. 35.

TABLE 15. EFFECT OF CLOGGED SPARK ARRESTERS UPON THE VELOCITY OF AIR FLOWING THROUGH A LARGE MODEL CHIMNEY.

Arrester No.	Velocity of air in chimney ft. per min.					Percent of open chimney velocity ft. per min.				
11	230	30	100	50	100	54.1	5.3	12.8	4.9	7.0
22	360	470	595	660	860	84.7	82.5	74.0	64.0	60.2
31	240	380	538	510	595	56.5	66.6	66.8	49.5	41.6
32	195	260	360	380	500	45.9	45.6	44.7	36.8	35.0
33	160	240	295	360	375	37.6	41.1	36.6	35.0	26.2
34	180	250	335	365	450	42.4	43.8	41.6	35.4	31.4
37	300	490	640	720	915	70.6	86.0	79.5	69.9	64.0
38	330	490	625	760	970	77.6	86.0	77.7	73.9	67.8
41	325	530	674	810	1010	76.5	93.0	83.6	78.6	70.7
42	320	500	640	800	990	75.4	87.7	79.5	77.7	69.2
None	425	570	805	1030	1430					

The clogged spark arresters affected the pressure and velocity of the air flowing in the chimney. The static pressure in the chimney was constant throughout the height of the chimney when the clogged arresters were used. This was due to the fact that the blower would build up a constant pressure, the magnitude of which depended upon the resistance offered by the arrester to flow of air.

The velocity of the air flowing through the arresters was reduced to as low as 4.9 percent of the original velocity. Arrester Nos. 41, 42, 38 and 37 gave the best results throughout the test.

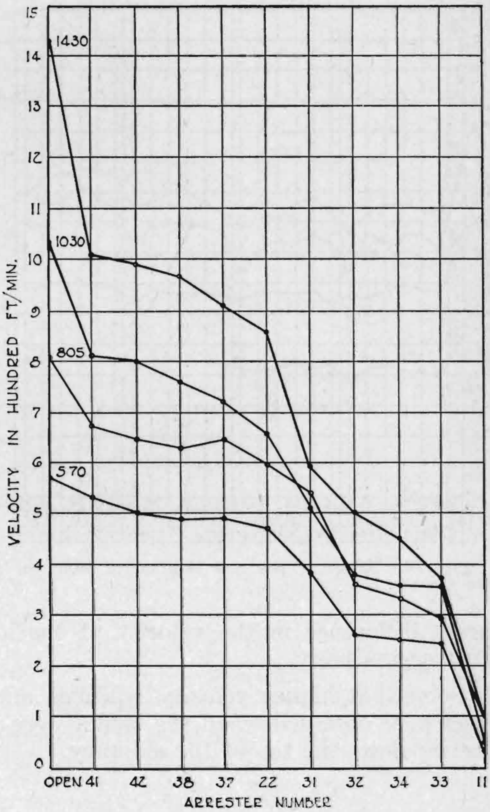

Fig. 35. The effect of clogged spark arresters upon four different velocities of air flowing through a large model chimney.

THE EFFECT OF SIZE AND LOCATION OF BAFFLE IN A NO. 38 ARRESTER UPON THE FLOW OF AIR IN A LARGE MODEL CHIMNEY

The set-up for testing the arrester was practically the same as that used to determine the effect of clogged arresters upon the flow of air in a large model chimney.

The sizes of flat metal baffles selected for use in the test are as follows: 4.5″ × 8.5″, 5.5″ × 9.5″, 7″ × 11″ and 7.5″ × 11.5″. Tests were made at air velocities of 530, 853, 1,114 and 1,510 feet per minute. The mesh of the arrester was completely clogged. The air was prevented from escaping between the bottom of the arrester and the top of the chimney by calking the crack. Three pressure readings were taken at each location in the chimney and averaged to get the velocity recorded in table 16. The velocity of the air was determined by averaging readings taken in each corner and in the center. Three such readings were averaged to get the mean velocity reading recorded in the tables.

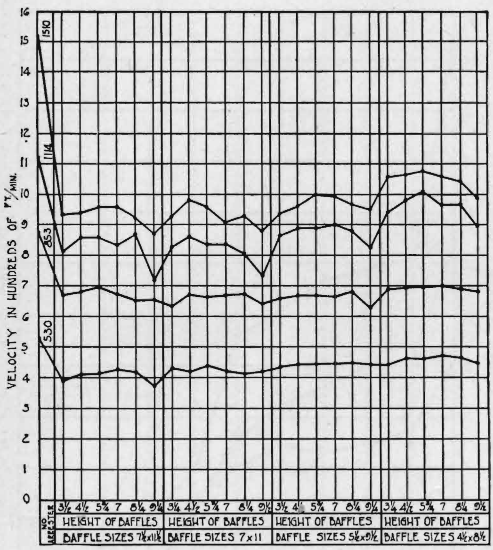

Fig. 36. Effect of size and location of baffle on air velocity.

Neither the location nor size of the baffle produced any great difference in the velocity of the air for any given open chimney velocity.

Somewhat higher velocity readings and lower pressure readings were obtained when the baffles were located $4\frac{1}{2}$, $5\frac{3}{4}$ and 7 inches above the top of the chimney.

THE EFFECT OF SPARK ARRESTERS UPON THE FLOW OF GASES IN A NATURAL DRAFT CHIMNEY

The preceding tests give values for the restriction to flow by the various arresters but were made under a reversal of actual pressure conditions.

The principal objective of this investigation was to study the

TABLE 16. THE EFFECT OF SIZE AND LOCATION OF BAFFLE IN A NO. 38 ARRESTER UPON THE FLOW OF AIR IN A CHIMNEY.

Baffle		Air velocity in open chimney ft./min.															
		530				853				1114				1510			
		Pressure .001″ water			Air. vel. with arrester	Pressure .001″ water			Air. vel. with arrester	Pressure .001″ water			Air. vel. with arrester	Pressure .001″ water			Air. vel. with arrester
Size	Height	Min.	Max.	Av.		Min.	Max.	Av.		Min.	Max.	Av.		Min.	Max.	Av.	
4.5 x 8.5	3.25	27	29	28	440	60	60	60	682	120	121	121	938	149	160	153	1055
	4.50	21	21	21	457	58	60	59	692	114	119	117	978	144	149	147	1060
	5.75	20	21	20	457	60	60	60	697	117	119	118	1008	143	153	149	1073
	7.00	24	24	24	462	60	60	60	700	117	119	118	965	147	154	150	1055
	8.25	22	22	22	455	64	68	66	685	118	120	119	962	152	159	155	1040
	9.50	28	29	29	445	70	70	70	672	124	127	125	898	164	168	166	985
5.5 x 9.5	3.25	30	30	30	435	70	70	70	657	121	126	124	860	160	168	165	933
	4.50	30	30	30	447	70	70	70	672	123	128	124	888	159	164	161	954
	5.75	34	36	35	445	69	70	70	685	123	127	125	888	159	165	161	1000
	7.00	29	29	29	445	70	70	70	667	127	129	128	900	164	171	166	990
	8.25	30	30	30	445	70	74	72	642	131	133	132	880	167	171	169	967
	9.50	38	39	39	437	79	80	80	647	140	141	140	823	177	180	179	895
7 x 11	3.25	40	40	40	433	80	80	80	632	136	139	137	818	170	177	174	927
	4.50	33	35	34	427	76	79	78	662	130	130	130	855	167	171	170	980
	5.75	33	35	34	440	78	79	79	660	129	130	130	853	165	175	169	953
	7.00	36	39	38	422	80	80	80	662	130	130	130	832	167	173	169	905
	8.25	40	40	40	412	84	86	85	665	139	140	140	858	170	178	174	927
	9.50	45	45	45	417	93	96	95	637	151	152	151	720	176	181	179	877
7.5 x 11.5	3.25	39	40	39	392	84	87	85	650	143	147	145	825	165	170	167	930
	4.50	38	39	39	412	80	80	80	662	139	139	139	858	160	165	162	938
	5.75	39	39	39	417	79	80	80	665	139	140	139	838	160	170	164	955
	7.00	39	39	39	430	80	81	81	660	140	140	140	838	174	180	178	953
	8.25	40	40	40	417	87	88	88	675	149	149	149	805	175	177	176	920
	9.50	49	49	49	370	97	99	98	622	160	160	160	733	180	181	181	867

Each of the four baffles was tested at heights of 4.5″, 5.75″, 7″, 8.25″ and 9.5″ respectively from the bottom of the arrester at each of the given flue velocities. The results are presented graphically in fig. 36.

characteristics of a natural draft chimney operating under normal conditions with and without a spark arrester.

Theoretical draft is the maximum difference in pressure when the chimney gases are stationary and there is no flow or circulation within the chimney, when the chimney gas temperature is at its maximum and when the chimney itself is at its maximum height. Theoretical draft is purely a theoretical quantity and cannot be measured accurately by a measuring device.

Available draft is the theoretical draft less the amounts lost by the velocity of the chimney gases and also by the friction of the chimney gases on the interior walls of the chimney. It is the difference in pressure as measured by a draft gauge when the chimney is operating and the chimney gases are flowing freely.

Required draft is the sum of the draft losses through the fuel bed, boiler, turns and breeching.

Since the available draft may be measured very readily by means of a draft gauge the influence of spark arresters upon the available draft in a chimney will be discussed in this manuscript.

Before attempting to set up any testing apparatus some preliminary investigations were made on a chimney which was operating under ordinary conditions. The chimney selected for the first preliminary test was 2 $\times$ 2.5 brick in size and 35 feet high. A Quick Heater, Series F, No. 26, was connected to the chimney by means of a 7-inch pipe. Air entering the furnace was regulated by means of dampers. A 0.75″ $\times$ 0.5″ hole was drilled through the side of the chimney 24 feet above the grate level in the furnace to receive the jet for reading the velocity of the gases inside the chimney. Another hole was drilled into the chimney to receive the draft gauge connection. The draft gauge was connected to the opening in the chimney by means of a copper tube sealed in the opening in the chimney.

Results of the readings taken indicate that the velocity and static pressure varied considerably. The velocity varied from 350 to 400 feet per minute and the static pressure varied from —.015 to —.020 inch of water when there was a hot bed of coals in the furnace and the intake opening in the furnace was closed. The temperature 24 feet above the grate was 171° F. A second reading was taken when the intake door to the furnace was open. The static pressure or draft varied from —.020 to —.025 inch of water, and the velocity of the gases varied from 250 to 300 feet per minute. After a heavy firing the pressure was found to vary from —.03 to —.35 inch of water, and the temperature was above the 220° limit of the thermometer.

In a second preliminary test, a sheet metal chimney 8 inches in diameter and approximately 24 feet high was used. It was wrapped with a thin sheet of asbestos.

Heat was provided by an Ideal Vecto Heater, Series No. PP9. Holes 3/32 inch in diameter were drilled in the chimney, and over each hole was soldered a 3/16-inch copper tube to make a suitable connection for the draft gauge. The holes and draft gauge connections were located: one just outside the heater, one each 3 feet, 8 feet and 13 feet above the burner in the heater. A hole was drilled in the flue 8 feet above the heater to receive the thermometer. After the heater had been in operation for 1 hour, pressure readings were taken at the openings in the flue which were numbered consecutively from the top of the heater. The draft gauge reading in inches of water for location No. 1 was —.053; for location No. 2, —.045; for location No 3, —.025; and for location No. 4, —.017.

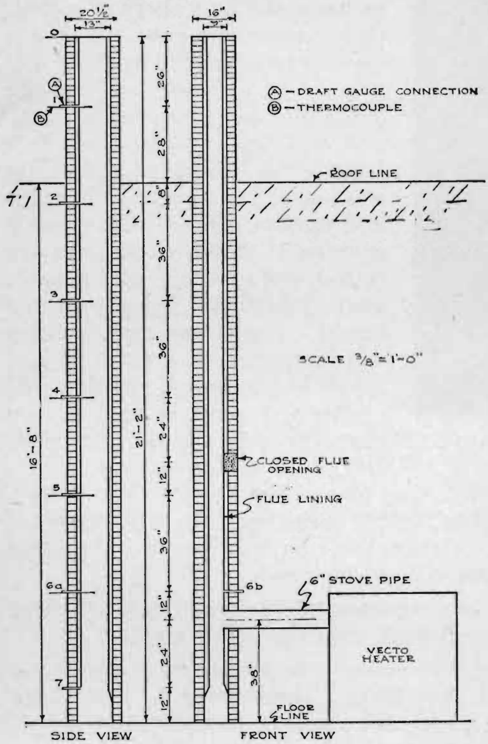

Fig. 37. Sectional sketch of brick test chimney.

The temperature in the flue was increased by allowing more fuel to enter the burner. The temperature could not be measured with the thermometer, but it was hot enough to melt the soldered joint just outside the heater. The draft reading in inches of water for location No. 2 was —.056; for location No. 3, —.030; and for location No. 4, —.025.

The greatest negative static pressure in a natural draft chimney is at the base nearest the source of heat. The static pressure varies considerably and the velocity of flue gases fluctuates widely. The velocity of the gases is greatest when the temperature difference is greatest. Wind blowing over the top of the chimney influences the velocity of the flue gases and the available draft in a chimney.

The principal tests were conducted with the chimney shown in fig. 37.

Draft gauge connections and thermocouples were installed at locations as indicated.

An Ideal Vecto Heater, Series No. PP9, as manufactured by the American Radiator Company, used to furnish the heat, was equipped with a gravity-feed kerosene burner.

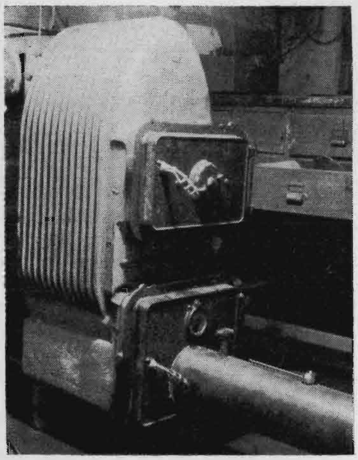

Fig. 38. Heater used in test.

The draft gauge which has already been described was used to calibrate and check the multiple manometer tube which was used to measure the draft or difference in pressure between the column of hot gases in the chimney and the outside air. Two liquids of different densities were used; a mixture of water and methyl alcohol with specific gravity of 0.826 for the heavier liquid, and kerosene with specific gravity of 0.807 for the lighter liquid. Eight manometer tubes were mounted on a sheet of plywood and mounted on the wall of the test room in such a way that the tubes could be tilted and all of the pans could be located together. (Figure 39). The tops of the heavier liquids were brought to the same heights and the series calibrated by means of a sensitive draft gauge. Calibrations were recorded on a large sheet of white paper placed behind the tubes.

The manometer tubes were connected to copper tubes located in the chimney with the end flush with the inside wall.

The bottom tube of the manometer was connected to a point in the chimney 1 foot above floor level. There being no flow of air or other gases past this point, the reading at this point served as a check against the readings at other points where there was a flow of gases. The top tube was left open to the atmosphere so that any difference in pressure within the room could be detected very readily. The remainder of the tubes were connected to points in the chimney as shown in fig. 37.

Flue temperatures were taken with thermocouples. The velocity of the air flowing through the intake of the furnace was measured by means of a thermocouple anemometer. The operation of this anemometer is essentially the same as that

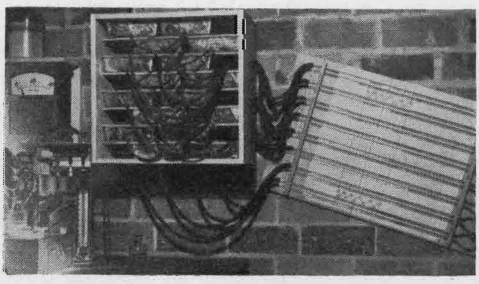

Fig. 39. Multiple tube manometer.

of a thermocouple. One junction of iron-constantan wire is heated by a heater coil while the other junction is cooled by the air. The electromotive force generated is detected by the galvanometer. The readings obtained were converted into feet per minute by use of a conversion chart.

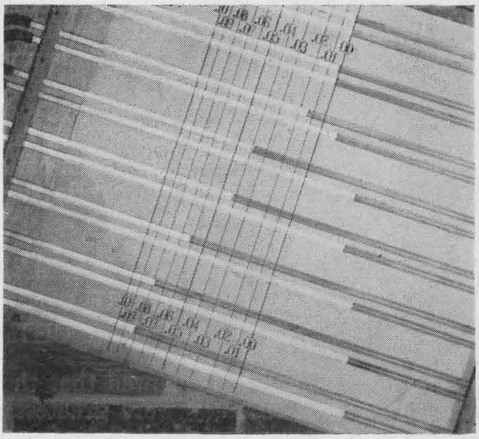

Fig. 40. Typical manometer reading.

A Taylor vane anemometer was employed to measure the velocity of the air currents within the chimney. The spark arresters used were completely clogged except for the free area. The velocity of the gases in the chimney was checked for a 5-minute period before an arrester was placed on the chimney. After an arrester was placed on the chimney the velocity was checked again for a 5-minute period and recorded. Each arrester was checked in this manner against the open chimney velocity and the data were recorded in table 17. The open chimney velocity shown in the tables is the average of three readings taken during the period of the test.

After completing test No. 1 the amount of fuel allowed to enter the burner was increased. Thirty minutes later the open chimney velocity was checked and found to be 116 feet per minute. All of the arresters were checked again in the same manner as described for test No. 1. The data were recorded as test No. 2.

TABLE 17. THE INFLUENCE OF CLOGGED SPARK ARRESTERS UPON THE VELOCITY OF GASES.

Arrester No.	Flue velocities — In a natural draft chimney (5-minute period)					
	Test No. 1		Test No. 2		Test No. 3	
	Ft. min.	% open	Ft. min.	% open	Ft. min.	% open
11	65.0	69.9	102.0	88.0	89.4	86.6
22	85.2	91.6	118.5	102.1	103.0	100.0
31	90.8	97.6	115.0	99.1	101.0	98.0
32	88.0	94.6	118.0	101.7	101.8	98.7
33	78.8	84.8	119.0	102.6	101.4	98.5
34	85.8	92.2	114.0	98.2	106.0	102.9
37	93.0	100.0	121.5	104.8	107.8	104.5
38	85.0	91.4	123.5	106.0	107.4	104.2
41	89.6	96.4	120.5	103.9	103.8	100.5
42	84.8	91.1	125.0	107.8	103.0	100.0
None	93.0		116.0		103.0	

A third test was made when the velocity of the gases in the open chimney was 103 feet per minute. The data for this test were recorded as test No. 3.

An examination of the data in the columns titled "percent of open chimney velocity" indicates that the velocity of the flue gases was increased when some of the arresters were used. In test No. 1, No. 37 arrester did not affect the velocity of the gases. When No. 11 arrester was used, the velocity was 60.0 percent; No. 33 was 84.6, and the remainder of the arresters gave velocities of more than 90 percent of the open chimney velocity. Only No. 11 reduced the velocity significantly in the last two tests.

THE EFFECT OF CLOGGED SPARK ARRESTERS UPON THE TEMPERATURE AND AVAILABLE DRAFT IN A CHIMNEY

The preliminary tests showed that the temperature and available draft in a chimney were greatest near the bottom of the chimney. This was investigated further and the effects produced noted by placing different types of clogged spark arresters on the chimney while it was operating under normal conditions and when there was no wind. The temperatures are shown in fig. 41. The furnace was allowed to burn for 2 hours to secure uniform temperatures.

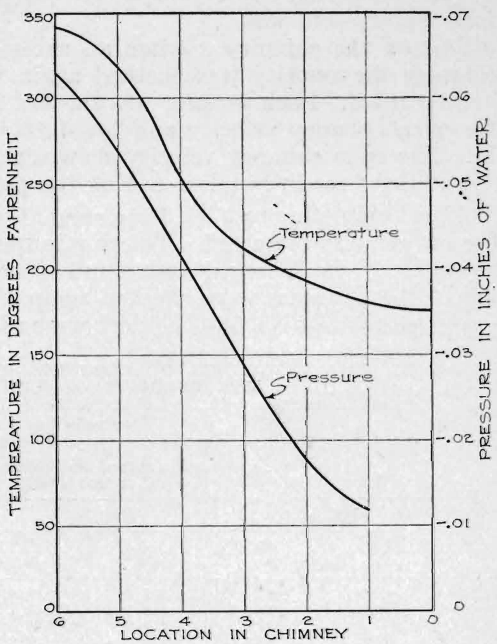

Fig. 41. Typical chimney temperature and pressure curves.

While the chimney was operating under normal conditions without an arrester, the temperatures at different heights in the chimney were checked and recorded. Figure 41 shows the available draft in the chimney when no arrester was used. Arresters of different types were then placed on the chimney. The temperature in the chimney for each arrester tested is shown in table 18.

TABLE 18. TEMPERATURE IN CHIMNEY WHEN EQUIPPED WITH DIFFERENT TYPES OF CLOGGED SPARK ARRESTERS.

Arrester No.	Temperature at different locations in chimney, degrees F.*						
	0	1	2	3	4	5	6
22	165	171	202	208	230	281	302
31	177	181	215	219	253	318	343
32	176	185	218	227	253	321	346
33	165	169	197	202	224	271	298
34	165	170	200	202	222	271	298
37	162	173	201	209	232	281	302
38	166	172	202	206	224	275	298
41	164	175	202	205	226	285	305
42	169	175	206	210	233	285	305
None	169	172	214	219	297	321	346

*See fig. 37 for location.

At the conclusion of the test just described the burner was opened to increase the temperature in the chimney. After 30 minutes the temperature was constant at the various observation points. Immediately after the draft was checked the burner was cut off and the intake to the heater was sealed airtight. Five minutes later the draft was checked again. Typical chimney temperature and draft or pressure curves are shown in fig. 41.

The effect of spark arresters upon the temperature in the chimney was pronounced. The temperature gradient in the chimney was affected by quantity of fuel used, completeness of combustion, temperature of outside air, temperature of air entering the heater, amount of air entering the heater and the location of the chimney. If the chimney were located inside a warm building the temperature gradient would necessarily be different from that of the same chimney located where the cold outside air could strike it.

The arresters did not have an appreciable effect upon the available draft in the chimney. Arrester No. 33 decreased the draft more than any of the other arresters.

Figure 41 indicates very clearly that the available draft in a chimney depends upon the temperature inside the chimney. In the 5-minute period the draft decreased —.03 inch of water.

The spark arresters affected the available draft in the chimney from 3.3 percent for No. 32 to 23.6 percent for No. 33. The average temperature during the test period varied from 168 degrees at the top of the chimney to 314 degrees at the base of the chimney. The temperature in the chimney was affected by the temperature of the outside air and velocity of wind.

THE EFFECT OF PARTIALLY CLOGGED SPARK ARRESTERS UPON THE AVAILABLE DRAFT IN A CHIMNEY WITH A WIND BLOWING INTO THE ARRESTER

Observation throughout the previous investigations indicates that wind has a decided influence upon the performance of a chimney. This coupled with the statement made by Stanworth (11), "In one way or other winds are the cause of at least 90 percent of smoky chimneys," has prompted this phase of the investigation.

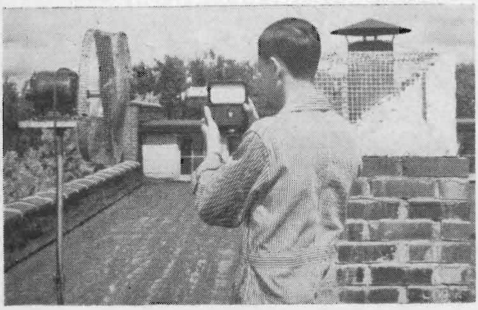

Fig. 42. Apparatus for testing the effect of side draft on performance of arrester clogged at one end and half of both sides.

The chimney and heater used were the same as in the previous investigation except that the draft reading was taken at the discharge of the heater. A wind velocity of 1,400 ft. per minute was furnished by a 16-inch propeller mounted on a 1/4 horsepower electric motor. A spark arrester clogged in one end and one-half of each side is shown in fig. 42. An arrester clogged in one corner is shown in fig. 43.

The heater was regulated to maintain a constant temperature in the chimney when there was an arrester in place and no side wind blowing. The available draft for this condition was recorded, the fan started and the draft at the end of 2 minutes recorded. The data for different types of spark arresters will be found in table 19. In the first test the wind was directed toward the end of the arresters. This condition will approximate what happens when the wind blows from one direction for a long period of time. The smoke and soot will be directed against and through one end of the arrester causing clogging on the side or end opposite the direction of the wind. If the wind continues to blow the smoke and gases against the clogged

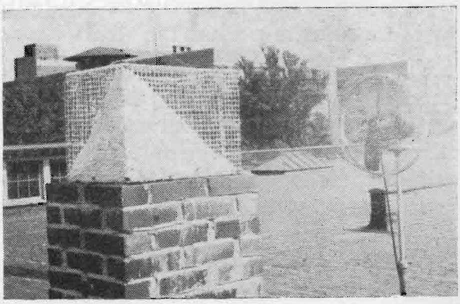

Fig. 43. Apparatus for testing the effect of side draft on performance of arrester clogged at the corner.

TABLE 19. THE EFFECT OF SPARK ARRESTERS CLOGGED IN SPECIFIED LOCATIONS UPON THE AVAILABLE DRAFT IN A CHIMNEY.

Draft in .001″ water—Wind as indicated

A. No.	Clogged in one end and one half of each side						Clogged in one corner					
	None	At A	None	At B	None	At C	None	At A	None	At B	None	At C
31	60	33	64	39	61	25	57	37	61	34	59	41
32	60	7	64	34	61	0	57	33	61	35	59	20
34	60	17	64	35	61	0	57	35	61	41	59	40
38	60	26	64	38	61	0	57	34	61	40	59	52
41	60	26	64	40	61	29	57	37	61	38	59	40
42	60	23	64	35	61	35	57	37	61	41	59	30
No arrester							63	61	61	59	64	60

All readings negative.

side or end of the arrester, eddy currents of air and flue gases will be produced within the arrester and directly over the top of the chimney. Such eddy currents will tend to retard the flow of the gases and even cause a positive pressure in the chimney. If the wind should blow into the end of an arrester at an angle above the horizontal and against the opposite side or end which has become clogged, very serious trouble will be experienced.

The test was repeated using wind direction B (fig. 44) for the arresters clogged in one end and one-half of each side. No noticeable effect was produced when the wind was in the side of the arrester, C, fig. 44.

An examination of the data indicates that side wind has a very serious effect upon the available draft in a chimney. When the wind was in direction A, and blowing directly into the clogged portion of the arrester, the available draft was reduced from —.060 to .007 inch of water when a No. 32 arrester was used. When the wind was in direction B, or at approximately 45

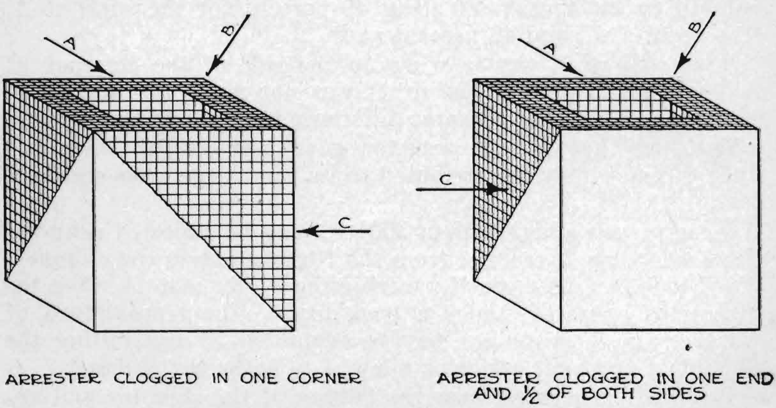

Fig. 44. Wind directions used in testing spark arresters.

degrees to the end of the arrester, the results were not so critical; however, the available draft was reduced from —.064 to —.034 inch of water when a No. 32 arrester was used. The most critical condition was produced when the wind was in direction A but tilted into the top of the chimney 10 degrees above the horizontal. In this case the Nos. 32, 34 and 38 arresters reduced the available draft to zero. Such a condition is typical of what would happen if the chimney did not extend high enough above the ridge of the roof. Trees and tall adjoining buildings are likely to produce the same effect. Chimneys which are located at the end of a single-story building which adjoins a two-story building usually give trouble for the same reason.

The No. 31 arrester exhibited the least tendency to affect the available draft when the side winds were used.

The investigation was continued by clogging the arresters only in one corner, fig. 43. This degree of clogging would not be so critical, yet it would be typical of a common type of clogging and could occur after the arrester had been in use for only a very short while.

The equipment and testing procedure used in this test were the same as that previously described, but the wind velocity was increased to 1,700 feet per minute.

The fan was then placed so that it would force the wind at an angle of 45 degrees to the top of the chimney. Such a direction of side wind would be duplicated by wind blowing up the slope of a roof and striking the top of the chimney.

Arresters clogged only in one corner have a decided effect upon the available draft in a chimney. In the test with wind at A, the available draft was reduced from —.057 to —.033 inch of water when a No. 32 arrester was used. When no arrester was used the draft was reduced only —.003 inch of water. There was not a great deal of difference in the results from different directions of wind in this series of tests. However, the draft was reduced on the average of about 40 percent for the wind at A, 40 percent at C, and 43 percent at B.

When the wind was blowing up the side of the chimney at an angle of 45 degrees the draft was not much affected. Not more than —.003 inch of water difference in pressure was noticed.

The fact that No. 38 arrester gave best results when the wind was at C may be attributed to its very large cross-sectional area.

A temperature higher than 500° F. may be expected near the point where the breeching from the furnace enters the chimney. This would be true especially during the winter months when the furnace is operated under a peak load. The temperature of the gases in the chimney may be regulated by controlling the amount of fresh air which is allowed to enter the chimney.

The draft is greatest near the bottom of the chimney and approaches atmospheric pressure at the top of the chimney.

In the tests using a kerosene heater the highest temperature recorded was 500° F. and the available draft at that instance was —.088 inch of water. Most of the tests were made while the maximum temperature in the chimney was around 300° F. Under these conditions there was not a large quantity of gases to be carried from the chimney. As a result the spark arresters did not have any great effects upon the performance of the chimney.

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